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Protective Skins for Composite Airliners

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April 2014

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1 Introduction

Current design of composite structures requires overdesigning to provide capacity to absorb impact and operate in hot, humid environments. Extrapolating progress in composites technology out three aircraft generations to the year 2035 results in a significant weight reduction but does not support a step change in weight reduction and fuel burned reduction to meet the requirements of NASA's Fundamental Aeronautics Program/Subsonic Fixed Wing Project N+3 research program.

As part of work in Phase I of the N+3 program, when pushed to find a way to get the last seven percent fuel burn reduction, Cessna turned the problem around and asked how to meet the structural requirements without overdesigning the structure. What if the primary structure is designed without any weight penalties ("knock downs"), and protective skins are used to meet the impact and hot, humid requirements? What if multiple requirements are met by one material in the protective skins? What if the external impact absorbing material also provides the acoustical treatment? What if the external protective skin can replace the thermal insulation? What if the impact damage is visible unlike many of today's composite structures? What if paint is replaced by an aesthetic film, allowing both attractive decorative outer surfaces and smooth surfaces which facilitate natural laminar flow? Could the result be a step change in weight and fuel burned reduction? NASA has provided the funding for Cessna to begin to answer these questions through funding for this research contract (NNC10CA36C Protective Skins for Composite Airliners).

The goal of this research is the development of potential concepts for protective skins which enable natural laminar flow and perhaps significant weight reduction in the aircraft's primary structure. The primary structure carries the load. The protective skin is needed to absorb impact damage and to provide environmental protection. The STAR-C^2 concept should be responsible for <u>smoothing</u> out bumps or gaps, providing <u>thermal</u> insulation, <u>absorbing</u> impact and <u>acoustic</u> energy, <u>reflecting</u> ultraviolet and infrared radiation, <u>conducting</u> large amounts of electrical current (for lightning strike), and providing a <u>cosmetic</u> or appealing surface.

The outcome of this research program is proof of the feasibility of the STAR-C^2 concept, recommendations to NASA on future materials research and development by material suppliers to support the STAR-C^2 concept, and recommendations on a potential research path to ensure that the STAR-C^2 concept is capable of being applied as soon as it is ready.

The research program was structured in two halves. During the first half of the program, the following activities were accomplished: defining the metrics and requirements for the protective skins; conducting a material search and developing the material composition for the protective skins, writing the test plans, conducting the tests, and analyzing the test data, and finally, using the collected test data, selecting the best materials for an improved set of STAR-C^2 protective skins. Test articles developed during the first half of the program are known as first-generation test articles, and test articles developed in the second half of the program are second-generation test articles. The second half of the program included building and testing the second-generation test articles, analyzing the data, and developing conclusions and recommendations concerning the feasibility of protective skins for composite airliners. Testing conducted in both halves of the program included impact, electromagnetic effects, aesthetics and smoothing, and thermal. Acoustic testing was also conducted for the second-generation test articles.

2 Background

Cessna Aircraft Company led the vehicle configuration development in a NASA N+3 Phase I research project while partnered with General Electric Aircraft Engines (prime contractor) and the Georgia Institute of Technology (NASA Contract NNC08CA85C). Aircraft and propulsion technologies that enable efficient and environmentally friendly transportation aircraft for the 2030 to 2035 time period were explored throughout this previous effort. A transportation system scenario and an advanced aircraft that satisfies all of the NASA research objectives for N+3 aircraft was developed and presented in the Phase 1 contract report (Reference 1).

The penultimate 2035 advanced aircraft developed during the NASA N+3 Phase 1 research project made use of advanced turboprop engines, an advanced composite airframe, and a vehicle shape that promotes natural laminar flow. While meeting all of the NASA goals at that time for reductions in nitrous oxide emissions (NOx), noise, and balanced field length, the configuration was short of the fuel burn reduction goal by nearly seven percent. In order to fully satisfy the fuel burn reduction, a novel protective skin concept was proposed. Table 1 shows the projected benefits of each of the technologies as a function of time. The protective skin (new conductive skin) shown in the 2030-2035 column of Table 1 provides an additional seven percent weight reduction.

With the anticipated benefits of the protective skin, the final aircraft concept (see Figure 1 and Table 2) was able to nearly meet the fuel burn reduction requirement as shown in Table 3. The technologies that enable this breakthrough performance and hence are relevant to NASA's subsonic fixed wing research include (1) advanced turboprop engines for reduced fuel burn, (2) laminar flow for drag reduction, and (3) advanced composite structures and systems for a reduction in vehicle empty weight.

Figure 1: The 2035 20-passenger advanced airliner.

Table 1 - Projected Savings of Various Technologies as a Function of Time

Aircraft Weight Groups	% of B-20 Empty Weight	2010 Composite Aircraft - Materials from 2000s	2015-2020 Composite Aircraft - Materials from 2010s	2030-2035 Composite Aircraft - Materials from 2020s	Technical Approach to 2035 Aircraft
Wing	15.60%	30.00%	35.00%	39.20%	New conductive skin reduces risk & supports accoustic, thermal, and some ice protection functions
Tail	5.16%	30.00%	35.00%	44.00%	
Fuselage	24.16%	25.00%	30.00%	34.00%	
Propulsion	18.98%	0.00%	0.00%	29.67%	Advanced engines reduce weight & fuel burn
Landing Gear	5.49%	0.00%	0.00%	15.00%	Systems, landing gear, & nacelles benefit from transition to electric systems, application of new materials, and optimized integration & installation concepts
Nacelle & Air Induction	2.71%	0.00%	0.00%	20.00%	
Surface Controls	1.88%	-15.00%	0.00%	15.00%	
Hydraulics	1.28%	-15.00%	0.00%	100%	
Electrical	5.41%	-35.00%	0.00%	15.00%	
Avionics and Instruments	3.95%	-35.00%	30.00%	60.00%	Avionics & instruments benefit from panel mount integration & continued breakthroughs in commercial electronics
Furnishings & Equip	10.48%	-60.00%	0.00%	29.19%	Some functions for accoustic damping, thermal insullation, ice protection, & paint moved to wing, tail, and fuselage weight groups (New Conductive Skin)
Air-conditioning & Anti-Ice	4.06%	-15.00%	0.00%	26.34%	
Paint	1.12%	0.00%	0.00%	100%	
Total % Savings	**0**	**1.60%**	**15.47%**	**33.11%**	
Risk	Application of aluminum structure & system integration technology	Application of current composite & system integration technology	Improved Materials, EMI, Lightning, & Sys. Integration	Conductive, Protective, & Health Monitoring Skin	

Table 2 - 2035 Final Configuration Descriptive Parameters

Parameter	Value
Wing Area, sq ft	203.6
Thrust per Engine, lbs	3,353
Total Fuel, lbs	1,494
Fuel Fraction	0.10
Balanced Field Length, ft	3,642
Empty Weight, lbs	7,636
Basic Operating Weight, lbs	8,325
Ramp (Gross) Weight, lbs	14,664

Table 3 - 2035 Final Configuration Performance against the NASA N+3 Phase II Metrics

Metrics	
Fuel reduction compared to baseline B-20, %	68.9
Cert Noise: Cum Margin Below Stage 4	74 EPNdB
LTO NOx: Margin to CAEP/6 6000 lb FN Req't	77% margin
Field Length: Margin N+3 Airport Req't, ft (below 4,000 ft)	358.0

The novel protective skin proposed in Phase 1 and under study for this Phase II contract effort enables natural laminar flow and a significant weight reduction in the aircraft's primary structure. The protective skin is needed to absorb impact damage and to provide environmental protection. This skin should be responsible for <u>smoothing</u> out bumps or gaps, providing <u>thermal</u> insulation, <u>absorbing</u> impact and <u>acoustic</u> energy, <u>reflecting</u> ultraviolet radiation, <u>conducting</u> large amount of electrical current, and providing a <u>cosmetic</u> or appealing surface (STAR-C²). The STAR-C^2 protective skin is not a self-healing skin – rather, the STAR-C^2 concept should allow damage requiring repair to be visually detected, not hidden.

Aircraft weight savings associated with a STAR-C² skin can be attributed to a change in the failure criteria for the primary structure and a more efficient approach to the design for environmental rather than load bearing requirements. Traditionally, primary composite structure must support ultimate loads after they have been subjected to damage and a hot, wet environment. If a STAR-C² skin can be designed to absorb some level of impact damage and reduce the moisture and/or temperature environment of the primary structure, then the primary structure need not carry additional material to maintain loads in harsh environments. Additional weight savings can be achieved if the STAR-C² skin can be designed for less weight than the current material system that is defined by the paint system, the acoustic treatment, the thermal insulation, and the lightning strike protection.

Although the motivation for STAR-C^2 skins was small airliners like those developed in the Phase I study, it is reasonable to expect the STAR-C² skin concept to benefit composite aircraft of any size. Different aircraft and different portions of an aircraft would be expected to benefit differently. For example, portions of an aircraft that are exposed to hail damage could be expected to benefit more than portions that are naturally sheltered. Given the potential for the integration of active health monitoring and aircraft systems like ice protection in a STAR-C² skin, all aircraft are expected to receive a meaningful benefit from this new concept. The concept also facilitates the integration of other subsystems into the surface of the aircraft structure.

3 STAR-C^2 Concept and Technical Approach

Traditional composite structures are designed to meet requirements for flight loads, for high temperature conditions, for wet environments, and to withstand impact damage. The requirements for hot, wet, and impact add weight to the structure. Typically acoustic treatment is required on the inside of

the fuselage to meet noise requirements in the cabin, and filling/fairing, lightning strike material, and primer/paint are required on the outside to meet the remaining requirements for composite structure as shown in Figure 2.

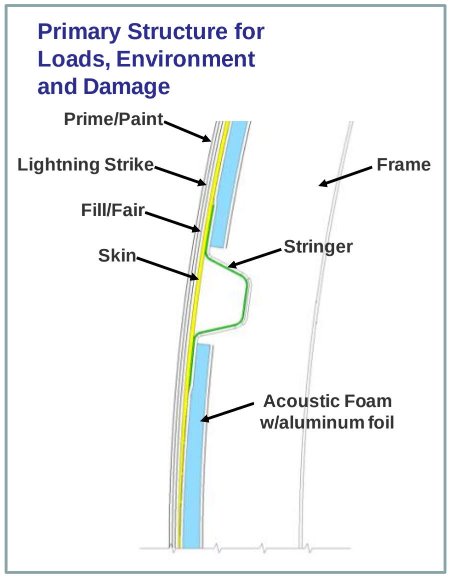


Figure 2: Conventional composite fuselage buildup.

Another way of portraying the material buildup of a conventional composite fuselage is by examining the functional decomposition as shown in Figure 3**.** The acoustic treatment reduces the noise inside the cabin to acceptable levels. The composite primary structure performs the functions of loads, thermal resistance, moisture barrier, and impact absorption; in order to perform all of those functions, the primary structure must be overdesigned (i.e., heavier). The filler/fairing performs both a smoothing and cosmetic function, the metal mesh performs the lightning strike function, and the outer layer of paint performs the smoothing, cosmetic, and reflection functions. The acoustic treatment is located inside the primary structure while the filler/fair, metal mesh, and paint are all outside of the primary structure.

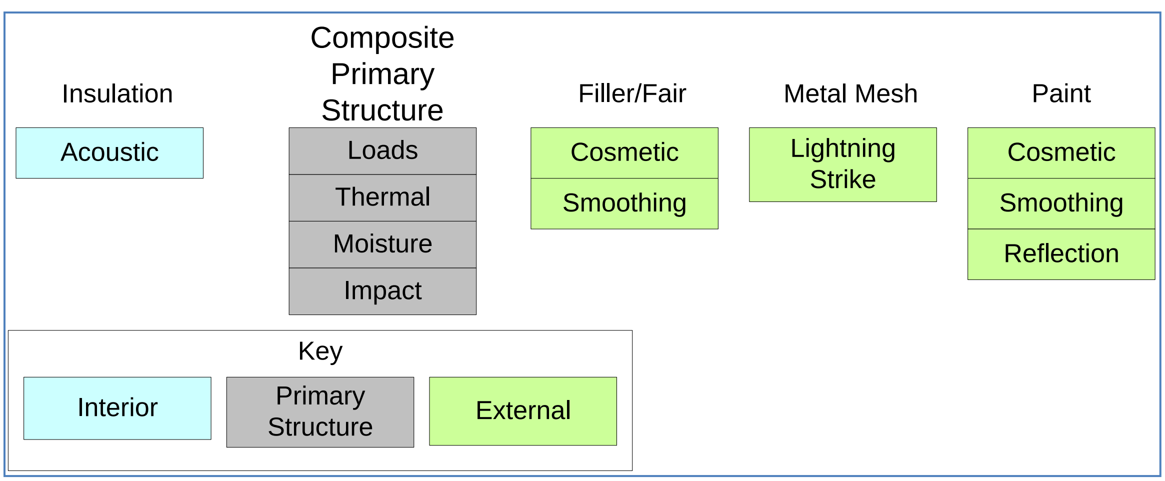


Figure 3: Functional decomposition of conventional composite fuselage.

Improvements in composites technologies (with the typical functional decomposition shown in Figure 3) projected to be available in 2035 improved the performance of the 20-passenger airliner under study during Phase 1 but did not succeed in meeting NASA's goal of 70% reduction in fuel burned. Creative thinking was required to find a way to reduce aircraft weight even further and to facilitate natural laminar flow to reduce the drag. One result of that thinking was the STAR-C^2 protective skins. The approach is to design the primary structure only for loads, move the acoustic treatment outside the primary structure, and combine as many functions as possible in each layer. A concept with two layers (energy absorbing foam and conductive skin) is shown in Figure 4. Two was thought to be the minimum number of layers possible; however, one material identified and tested (Polydamp Hydrophobic Melamine with metalized PEEK (polyether ether ketone) skin) was made up of two layers which came already attached to each other. One goal of this research is to determine the actual number of layers necessary to meet all of the requirements while also meeting the weight and cost targets.

A functional decomposition of the two-layer concept is shown in Figure 5**.** The composite primary structure is thinner and weighs less because the only requirement is to carry the loads. The core material meets the requirements for impact, thermal (high temperature), and acoustic. The outermost film layer provides the smoothing/cosmetic function previously provided by the filling/fairing material, lightning strike protection, and the cosmetic/smoothing function previously provided by the filling/fairing material and paint. There is no layer internal to the aircraft since the core material is meeting the acoustic requirement. The functional requirements for a smoothing surface layer, for protection from lightning strike, and for protection from a specified amount of impact damage are considered critical or design requirements.

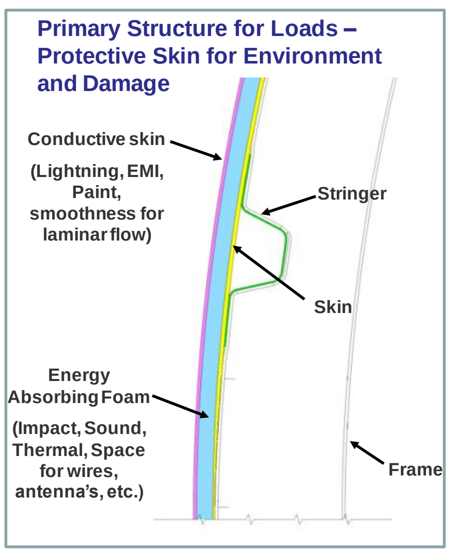


Figure 4: Potential concept for 2035 composite.

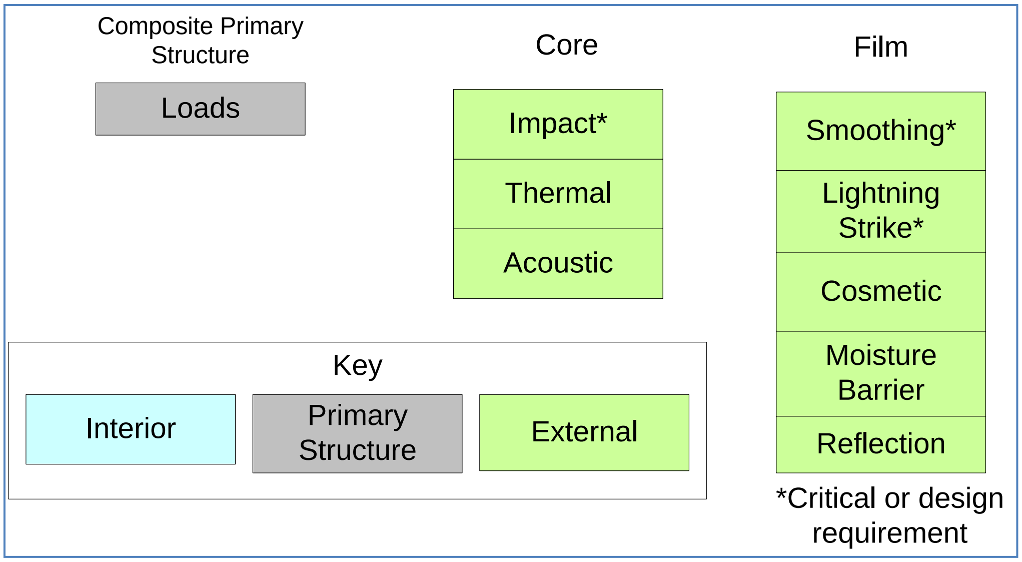


Figure 5: Functional arrangements for primary composite structure with protective skins made up of two layers.

To be successful, the total weight of the composite primary structure, core, and film needs to be less than the weight of the traditional 2035 composite fuselage with all of the associated materials. The other element necessary for success is being easy to install and repair. Ideally the protective skins should also make impact damage detectable from a walk-around inspection. Figure 6 shows a potential tile plus overwrap concept that enables the aesthetic coating to cover impact damage tiles that are easy to remove, repair, and/or replace. The best approach for a STAR-C^2 skin may be associated with material layers that provide all or part of the performance for each functional requirement. It is also recognized that the number of unique layers of material could vary based on the availability of materials and the assembly and installation process. The definition of each of these layers and the appropriate material properties for these layers is the goal of this research.

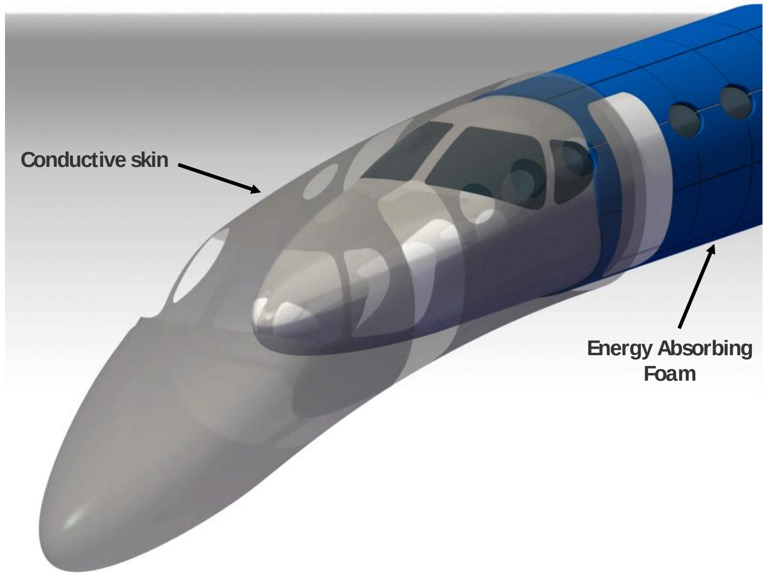


Figure 6: Candidate installation concept for a STAR-C^2 skin.

As defined for this research, STAR-C^2 is not a self-healing skin. Rather, the STAR-C^2 concept should allow damage requiring repair to be visually detected, not hidden. Visible damage after a bird strike when viewed from the front appears to be limited to the need to clean off the composite material as shown in Figure 7 while the actual damage to the hidden structure is quite significant as shown in Figure 8.

Figure 7: Front (outside) view of composite structure after bird strike.

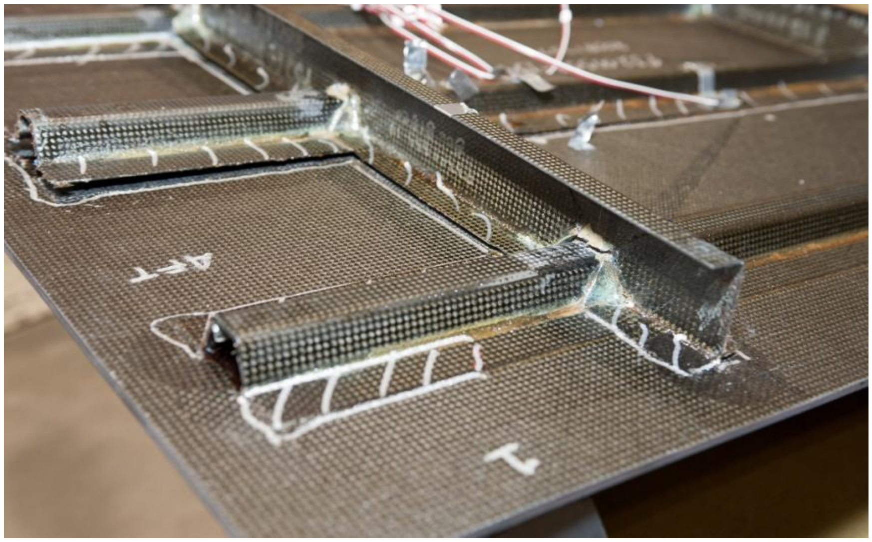


Figure 8: Rear (inside) view of composite structure after bird strike.

Currently available materials will be used to explore the contribution of each layer of a STAR-C^2 protective skin to the functional requirements, to identify candidate categories of materials, and to specify the properties of new materials that will lead to an optimum protective skin. The functional requirements for a smoothing surface layer, for protection from lightning strike, and for protection from a specified amount of impact damage are considered critical or design requirements. Consequently the analysis and test program is intended to provide insight into the best approach to satisfy these requirements with a STAR-C^2 skin that is defined by two or more layers of material. Once an acceptable approach to these requirements is established, the remaining functional requirements can be used to define a set of material requirements that leads to the largest weight savings. The most valuable STAR-C^2 skin is the one that satisfies many environmental protection needs, leads to an aircraft weight savings, facilitates laminar flow (perhaps the largest contribution to fuel burn reduction), and is easy to install and repair.

This research program is working to accomplish the following: (1) establish the technical requirements for the STAR-C^2 skin, (2) identify appropriate materials for this protective skin, (3) build representative test panels that include both structure and skin, and (4) verify through test the effectiveness of the selected materials at satisfying the technical requirements. The feasibility of a STAR-C^2 skin will be based on the ability of current or future materials to satisfy both the functional protection requirements as well as some weight targets that enable a significant benefit to a small airliner. The outcome of this research program is proof of the feasibility of the STAR-C^2 concept and recommendations to NASA on future materials research and development by material suppliers to support the STAR-C^2 concept.

4 Metrics

A set of metrics were identified to initially set goals for the STAR-C^2 protective skins and then to compare the actual parameters achieved with the goals. The metrics include areal weight, cost, thickness, and thickness. Each of the metrics will be described in the following subsections.

4.1 Areal Weight

The weights associated with traditional aluminum and fuselage structures include the weight of the fuselage, the weight of the acoustic treatment (which is included as part of the furnishings & equipment weight in Cessna's weight equations), and the weight of the paint. These estimated weights are shown in Table 4 for the current technology aluminum aircraft, for the 2035 composites aircraft, and for the 2035 composites aircraft with protective skins. The weight reductions for the 2035 airplanes led to reduced fuel weight which led to a smaller airplane. The fuselage weight for the 2035 composites with protective skins includes the primary structure and the protective skins. The weight is reduced compared to the 2035 conventional composites fuselage partly because the size of the overall aircraft has reduced and partly because of projected fuselage weight reductions. Similarly for the furnishings & equipment weight – the overall size of the aircraft is smaller and the acoustic treatment weight is eliminated. Paint for the 2035 protective skin aircraft is completely eliminated.

The fuselage wetted area of the current technology aluminum airplane is 1,164 ft^2; the fuselage wetted area of the 2035 airplanes is only 962 ft^2. As seen in the lower part of Table 4, the pounds per square foot decreases from 4.46 for the current aluminum fuselage to 3.14 pounds per square foot for the 2035 composite protective skins fuselage.

Table 4 - Weights of Components Affected by Protective Skins for Phase 1 Airliners

Component	Current Technology Aluminum (lbs)	2035 Conventional Composites (lbs)	2035 Composites with Protective Skins (lbs)	% Reduction from 2035 Composites 2035 Composites with Protective Skins
Fuselage	3,512	2,359	1,988	15.7%
Furnishings & Equipment	1,524	1,332	1,031	22.6%
Paint	156	103	0	100%
Total	5,192	3,794	3,019	20.4%
lbs/ft^2	4.46	3.94	3.14	20.3%

In order to meet the 70% fuel burn reduction, the weight of the 2035 composite with protective skins fuselage must be 1,988 lbs. The fuselage is composed of both primary structure and the protective skins. Separating out weight of the primary structure from weight of the skins is not feasible since the actual composites available in 2035 are unknown. Instead, working parametrically, it is possible to allocate weight between the primary structure and the skins by using percentages (i.e., 90% of the weight is primary structure and 10% is skins, to 70% of the weight is primary structure and 30% is skins). The line in Figure 9 represents the potential protective skin areal weight targets (in lbs/ft^2) depending on the protective skins' percentage of total fuselage weight. While providing the relationship, this approach does not suggest an appropriate range or target for the protective skins weight.

Another approach for estimating a weight target is to address what will be eliminated directly by application of the STAR-C^2 skins. Current acoustic/thermal insulation on today's aluminum aircraft accounts for approximately 0.40 lbs/ft^2 of the fuselage cockpit/cabin area (all fuselage area except the tail cone). Filler, primer, paint, and lightning strike material on today's composite aircraft represents about 0.17 lbs/ft^2 on the total aircraft. The cockpit/cabin comprises about 25% of the total aircraft wetted area.

Combining these weights gives a target of 0.275 lbs/ft^2 for the protective skins. This target does not include any installation hardware, and it will have to be allocated between the actual layers of skin developed.

The range for weight target suggested here covers the protective skins being 5% of the total fuselage weight up through being 30% of the total fuselage weight. Although no formal estimates of the potential decrease in weight for removing the harsh environment and impact damage could be found in the literature, one experienced estimate was that a reduction in strength required of 40% would result in approximately a 10% reduction in fuselage weight, giving a protective skin weight of 0.21 lbs/ft^2 which would indicate that 0.275 lbs/ft^2 is at least of the right order of magnitude.

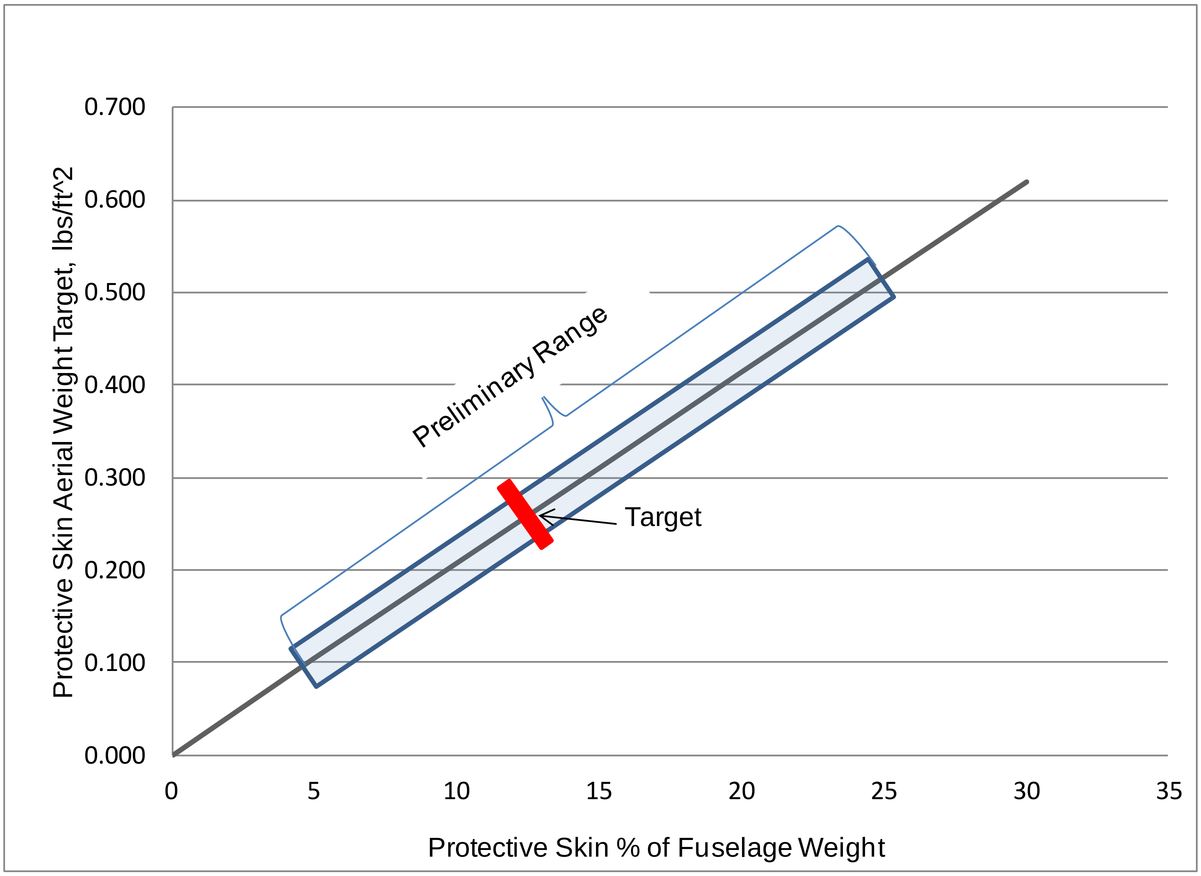


Figure 9: Potential weight allocation for protective skins.

Once actual materials were considered (including adding an impact spreading shell layer to the impact absorbing core material), the STAR-C^2 protective skins weight allocations and range was revised. The breakdown of weight ranges for core, shell, and film materials is shown in tabular form in Table 5, while the overall range and target are shown in Figure 10**.** The target holds at 0.275 lbs/ft^2 but the range has been reduced from 0.140 lb/ft2 at the lower end to 0.450 lb/ft2 at the upper end, corresponding to the protective skins being from 7% to 27% of the total fuselage weight.

Table 5 - Revised Protective Skin Weight Estimates and Target

	Weight (lbs/ft^2)		
	Low	High	
Core Material	0.040	0.200	
Shell Material	0.050	0.100	
Film	0.050	0.150	
Total	0.140	0.450	0.275 lbs/ft^2

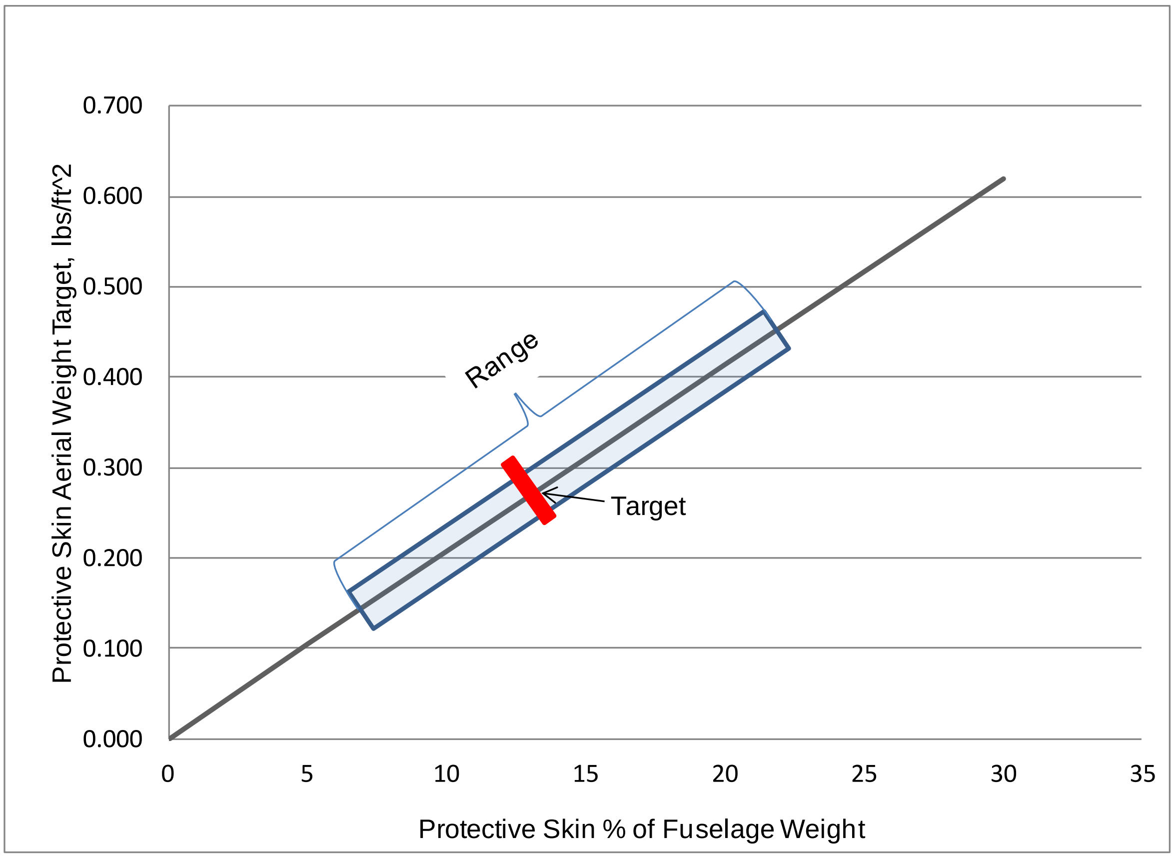


Figure 10: Final protective skin weight target and range.

4.2 Cost

The cost of materials which will exist in 2035 is not known. Nor is it possible to generate credible estimates of what savings from aircraft performance can be allocated to the cost of skins (a “should cost” exercise). Additionally, the difference between obtaining sufficient materials to build test panels compared to buying material in quantity to cover multiple aircraft can be very large, making research cost targets at this early research stage of limited value.

Because this is a fixed price contract, the cost limits for the protective skins were identified in the proposal for this research. They are shown in Table 6. There is no lower limit; the upper limits are based on Cessna’s definition of commercially available and affordable. The total cost for the skins must not

exceed \$85/ft^2. If layers are combined, the total cost can be redistributed to set upper limits for the materials actually used.

Table 6 - Cost Limits for Protective Skin Layers

\$40/ft^2 for Aesthetics/Smoothing Layer
\$30/ft^2 for EMI/Lightning Strike Layer
\$5/ft^2 for Impact Load Distribution Layer
\$10/ft^2 for Impact or Energy Absorbing Foam

4.3 Thickness

There is no minimum limit on thickness of the protective skins (where thickness is the distance from the outer surface of the primary structure to the outer surface of the protective skins). The upper limit is set by aerodynamic considerations. There will be some decrease in fuselage primary structure thickness due to the absence of the harsh environment and impact requirements. There will be some increase in thickness of the fuselage due to addition of the protective skins. Since the decrease in primary structure thickness is unknown and the increase in drag/decrease in range due to increases in aircraft skin thickness is not easily determined, an educated target of protective skin thickness of 0.25 inches with a maximum of 1.0 inches thickness will be used during this research.

4.4 Number of Layers and Unique Materials

A key finding for this research will be the number of layers required to produce protective skins which meet all of the requirements. At this time, the minimum number is believed to be two layers. There is no maximum. In addition to the layers identified, methods to attach those layers to each other and to the primary structure will be required. Adhesives are a good candidate. The number of layers and the number of unique materials (including adhesives or other fastening materials) will strongly influence the cost of the skins. These two metrics will be tracked and reported on during the research.

4.5 Visible Damage

Impact damage which is sufficient to require repair should be visible with a visual inspection. Nondestructive inspection or other method could be used to determine the extent of any repair required. An attribute metric of yes/no will be used to track the ability of the STAR-C^2 skins to show visible damage.

4.6 Installation and Repair

In order for the protective skin concept to be feasible, the skins must install in a reasonable amount of time and repairs must be capable of being carried out in the field, again in a reasonable amount of time. Trades between cost, installation process, and repair process will be useful in developing STAR-C^2 concepts. For example, damage repair could take place in a local area for both the core material and the smoothing layer, in a local area for the core material with replacement of the entire smoothing layer, or with replacement of both the entire core material (or a core panel) and the entire smoothing layer. Which one of those repair methods is used will depend on the cost of the materials, how effective the repair is, and how long it takes to make the repair.

5 Requirements

The critical or design requirements for the STAR-C^2 skins are energy absorption (impact), smoothness, and conductivity (lightning strike). Other requirements include thermal, reflectivity, cosmetic, acoustic, environmental considerations, and other considerations. The environmental and other considerations will be used to guide the selection of materials, not to define the testing required.

Cessna has considerable experience with most of these requirements. However, there are two important differences between Cessna's current view of requirements and the requirements for STAR-C^2 skins. The first is the difference between current primary composite structure and primary composite structure protected by STAR-C^2 skins. Some requirements may be different (most likely lessened) because the skins must only protect the primary structure from the condition, not completely withstand the condition themselves. The second is the difference between business jets and airliners. There may be significant gaps between acceptable appearances on a business jet and an airliner.

5.1 Energy Absorption

One of the critical design requirements is the ability of the protective skin to absorb impact energy. Current composite structures are difficult because damage sufficient to require repair can occur but not be visible to the eye. Figure 11 (copied from AC20-107B2) shows the five categories of damage along with their associated design load levels. In the figure, BVID stands for barely visible impact damage, and VID stands for visible impact damage. Category 1 damage is allowable damage that may be undetected by scheduled or directed field inspection or allowable manufacturing defects. Category 2 damage can be reliably detected by scheduled or directed field inspections performed at specified intervals. Category 3 damage should be detectable within a few flights by operations or ramp maintenance personnel without special skills in composite inspection. Category 4 damage is discrete source damage from a known incident such as rotor burst, bird strikes, tire bursts, and severe in-flight hail; flight maneuvers are limited when Category 4 damage has occurred. Category 5 is severe damage which might be caused by severe service vehicle collisions with the aircraft, anomalous flight overload conditions, abnormally hard landings, maintenance jacking errors, etc.

The goal for the STAR-C^2 skins is to make sure that Categories 2, 3 and 4 damage are visible to the flight crew during their external inspection of the aircraft. Metallic aircraft do not have Category 2 requirements because all damage is at least Category 3 – aluminum dents easily. The STAR-C^2 material selection process needs to address this important issue. Category 2 requirements drive the vast majority of impact damage sizing. To eliminate the Category 2 requirements, the STAR-C^2 skins must show evidence of impact similar to aluminum.

The manufacturer of a composite aircraft must go through a process to determine the impact damage requirements for an aircraft. First, a threat assessment matrix (such as that shown in Table 7) considers all possible types of damage during ground-based and flight operations. Damage tolerance categories are assigned for each criteria identified (some forms of damage have more than one criteria), and appropriate responses are described. Figure 12 (copied from Reference 3) shows a Boeing assessment of all of the potential ground hazards capable of impact damage for a commercial airliner. The ramp can be a busy and dangerous place.

The next (and final) step is to assign impact requirements to zones of the aircraft depending on location of the zone and the impacts to which that zone might be subjected (see Figure 13 for a

representative business jet). Impact requirements are different depending on the aircraft zone. The representative impact requirement for this project is 180 in-lbs with a 1-inch impactor. A three-pound weight dropped from a height of 60 inches generates 180 in-lbs. Terminal velocity for 1" hail represents 13.3 in-lbs and 2" is 213 in-lbs. The requirement for 180 in-lbs was selected to represent 90-95% probability (less than 5-10% of occurrence). This requirement applies to the hail-ground zone on the aircraft (top of the aircraft).

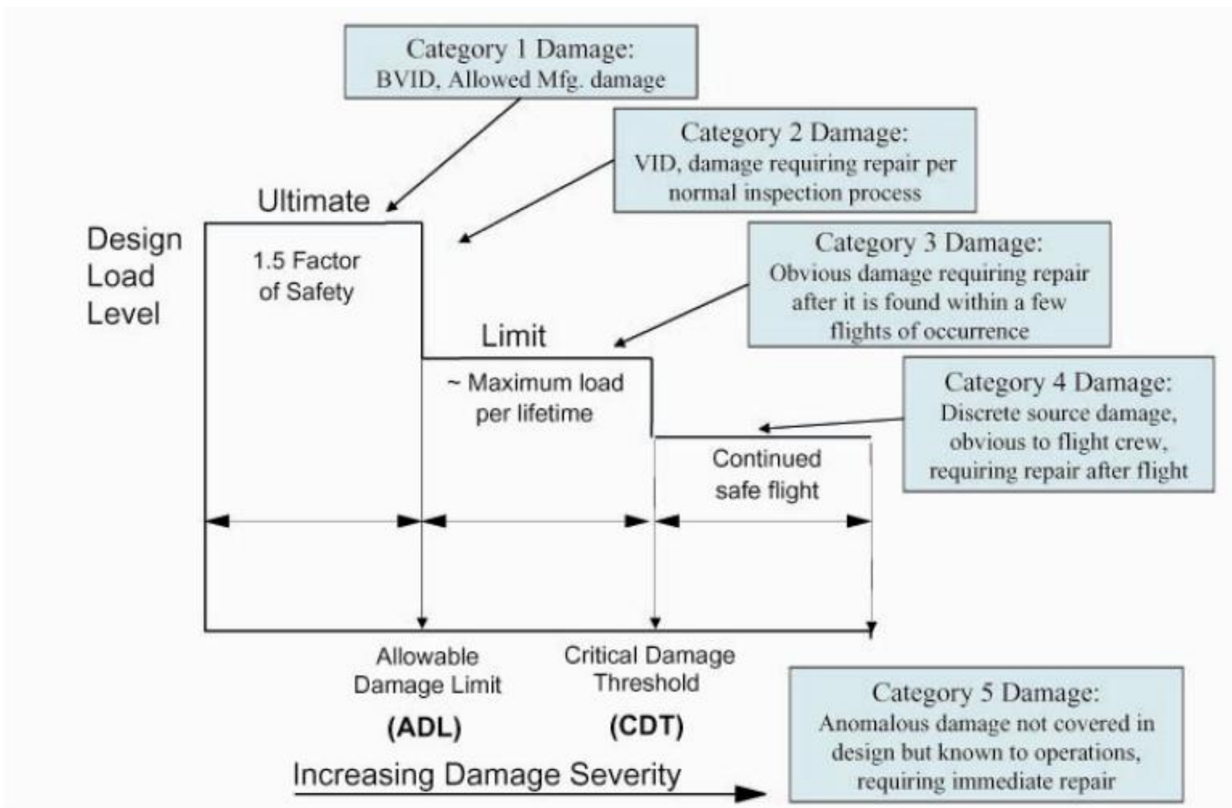


Figure 11: Schematic diagram of design load levels versus categories.

Table 7 - Sample Damage Threat Assessment Table

Threat		Operation	Damage Tolerance category 1	2	3	4	5	Criteria	Cessna Proposed Compliamce
Tool Drop	Small	Ground	X					Boeing: 48 in-lb normal to surface. 1" dia impactor	No visible damage. No damage growth for 3 DSG (Design Service Goal) accounted for Ultimate Design Allowable
	Large	Ground	→	X				Boeing: Up to 1200 in-lb or defined dent depth. 1" dia impactor	Up to VID to be found @ scheduled maintenance. No damage growth for 3 DSG (Design Service Goal) accounted for Ultimate Design Allowable
	Numerous	Ground	→	→	X			Multiple, superimposed impacts, clusters (large tool)	Up to VID other indicators with a high reliably detected by operations or ramp maintenance personnel. Limit loads, cycle in support Annual/100 hour Inspection
Blunt Force to Internal Structural Features		Ground	→	→	X			Failure of structural size and degree as related to event	Up to VID to be found during manufacturing or scheduled maintenance. Repaired before delivery or return to service
Ground Operation and Maintenance Equipment Collisions		Ground	→	→	→	X		Energy as requiremed to achieve Catergory 4 damage	BVID to Severe damage and/or other indicators with a high reliably detected by operations or ramp maintenance personnel
"Fail safety" Failure of Structural Segment		Ground/ Flight	→	→	X			Failure of structural segment, frame/ stiffener/ support with skin/structure	Analysis/tests shall demonstrate airframe to limit load and no detrimental damage growth in support of Annual/100 hour inspection. Segment defined by arrestment features
Material Degradation	Chemical or Environmental	Ground/ Flight	→	→	X			Failure of structural size and degree as related to event	Analysis/tests shall demonstrate airframe will sustain limit loading and no detrimental damage growth in support of Annual/100 hour inspection
	In-Flight Fire	Flight	→	→	→	X		Summary	Residual strength for "Get-Home" loads specified in the regulations
Hail	Ground Non-removable Structure	Ground	→	X				200 in-lb impact with simulated hail ball	Ultimate design strength, no moisture intrusion and no detrimental damage growth during 3 DSG for small hail
	Ground (NRS) Severe	Ground	→	→	X			Boeing: Up to 500 in-lb impact with simulated hail ball	Limit loading, no detrimental damage growth in support of Annual/100 hour inspection
	In-Flight	Flight	→	→	X			Simulated hail ball, Size and velocities bases on statistical data	Limit loading, no detrimental damage growth in support of Annual/100 hour inspection
	In-Flight Severe	Flight				X		Simulated hail ball up to a specific airspeed	Residual strength for "Get-Home" loads specified in the regulations
Lightning Strike	Nominal	Flight	→	X				Approx. 50th percentile strike energy level	Cosmetic only. Structural repair not needed Sealing/restoration of protection may be necessary
	Dispatch	Flight	→	→	X			Approx. 80th to 90th percentile strike energy level	Visually detectable damage. Immediate Lightning Strike mtl repair. Structural repair may be deferred to Annual/100 hour inspection
	High Energy	Flight				X		Strike level in accordance with zoning diagram	Protection of systems for lightning attachment. Continued safe flight
Runway Debris		Flight	→	→	X			Boeing: .50 " dia spherical object @ tangential tire speed	Limit design strength and no detrimental damage growth in support of Annual/100 hour inspection
Breaching of Pressurized Fuselage- Sudden Decompression		Flight	→	→	→	X		Structure, without regard of source, support sudden release of pressure.	Compliance is to be by analysis, supported by testing
Rotor Burst, Threats from Rotating Machinery		Flight	→	→	→	X		Structural damage from engineof rotating machinery failure	Residual strength for "Get-Home" loads specified in the regulations
Bird Strike		Flight	→	→	→	X		4 lb bird at Vc @ sea level, or .85 Vc @ 8,000 feet	Bird impact test articles or components representative of design
Exploding (Main) Tires		Flight	→	→	→	X		Simulated tire burst	Residual strength for "Get-Home" loads specified in the regulations
Category 5:		Flight					X	Flight Overload, Jacking Errors, Severe Vehicle Collisions, Loss of Parts (Causing Blunt Force)	

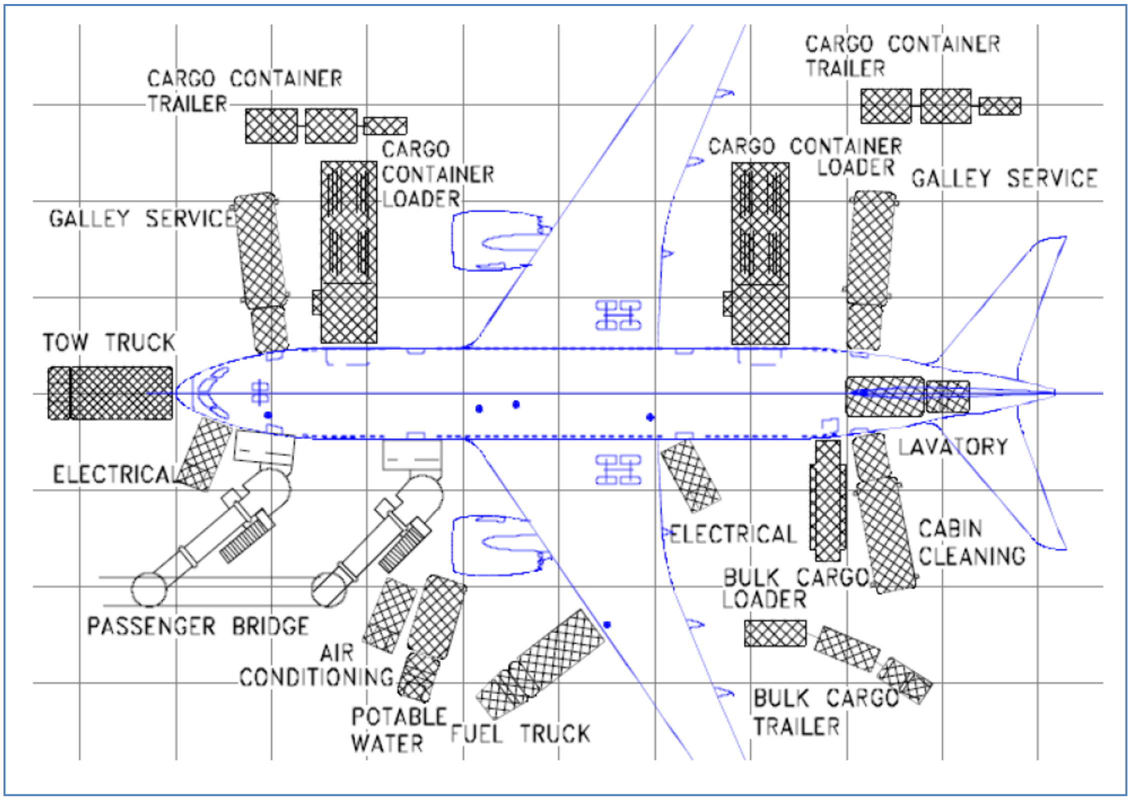


Figure 12: Threat assessment - ground support (copied from Reference 8).

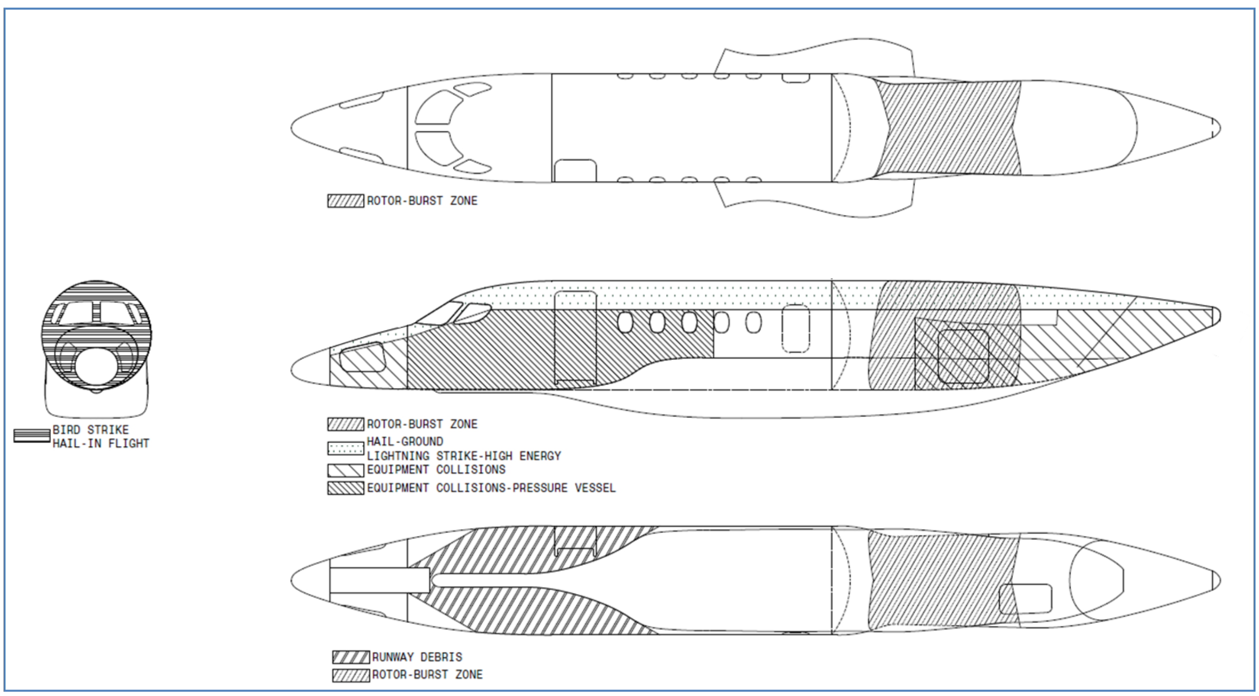


Figure 13: Sample threat assessment fuselage drawing.

5.2 Smoothness

The 2035 20-passenger airliner was designed for extensive natural laminar flow (see Figure 14). Great care was put into shaping the fuselage to bring area forward and to maintain maximum favorable pressure gradient. The cabin entry door was moved to the rear of the cabin out of the laminar flow area to avoid steps and gaps which might trip the flow and eliminate the drag reduction. The escape hatch was moved forward with the thought that it could potentially be covered with a film which would break in the unlikely event the hatch needed to be opened.

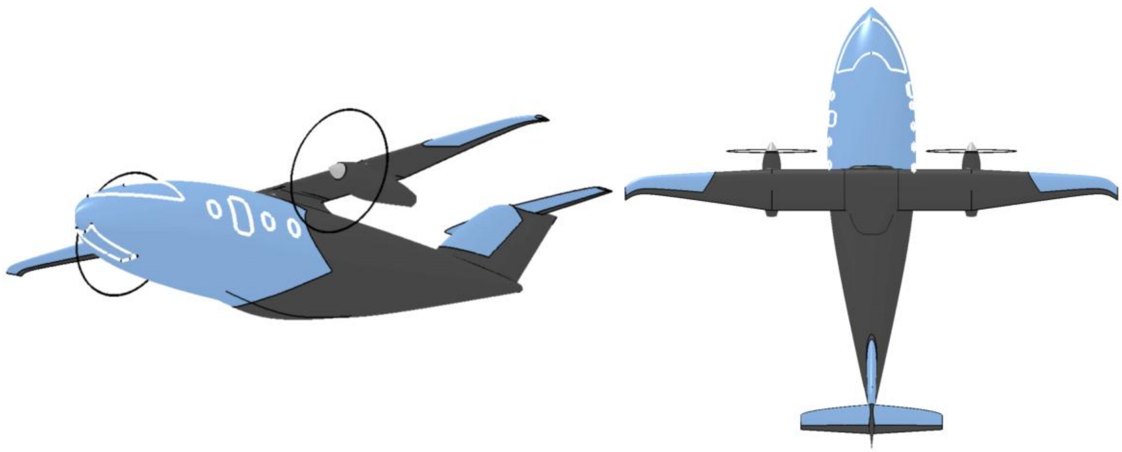


Figure 14: Projected areas of natural laminar flow (shown in blue).

There are three primary requirements for smoothness to support natural laminar flow in addition to designing the airframe shape to exhibit positive pressure gradients (which was done on the 2035 20-passenger airliner and which results in a radically different fuselage shape). The three additional requirements involve waviness, step heights, and gap lengths as described in Reference 4. The permissible sizes of waves, steps, and gaps are all a function of the Reynolds number and empirical relationships documented in Reference 4. Reference 5 (which is 20 years newer than Reference 4) confirms that shaping the aerodynamic surfaces for favorable pressure gradients does relax the allowable step and wave size while still maintaining natural laminar flow. The methods of Reference 5 require knowledge of the pressure distributions so application of the methods is not practical for comparison in this effort.

For the 2035 20-passenger airliner, the cruise Mach number is 0.55 at 39,000 ft. The wing is unswept and has a mean aerodynamic chord of 3.81 ft (wing span is 53.39 ft and Aspect Ratio is 14). Low airspeed and no sweep help increase the allowable waviness, step heights, and gap lengths to maintain laminar flow. Each of these parameter requirements will be discussed in the following subsections.

5.2.1 *Waviness*

The empirical relationship for allowable waviness is:

$$\frac{h}{\lambda} = \left[\frac{59000c\cos^2\Lambda}{\lambda R_C{}^{1.5}}\right]^{0.5}$$

where h and λ are defined in Figure 15. R_C is the Reynolds number based on chord. Λ is the wing sweep. The maximum allowable waviness is described as a function of wavelength λ in Figure 15. Reference 4 comments that, with the modern manufacturing technologies of 1985, all aircraft studied met the waviness requirements except at major structural joints where one or two widely-spaced waves would be present. Therefore, the waviness requirement is not expected to be significant in this development work.

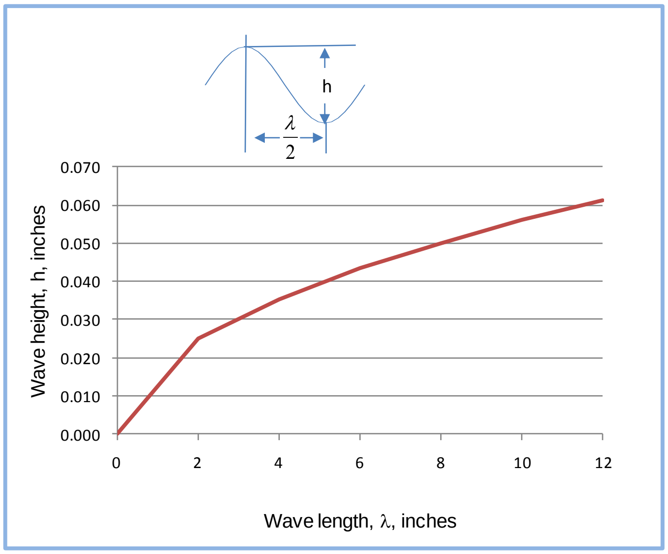


Figure 15: Waviness limits.

5.2.2 *Steps*

There are two potential types of steps as defined in Figure 16: rounded steps and square steps. In the rounded step, the radius of curvature is approximately equal to the step height, h. The equation defining the maximum step height to maintain laminar flow for the square step is:

$$h < \frac{1800}{R'}$$

and for the rounded step is:

$$h < \frac{2700}{R'}$$

where R′ is the unit Reynolds number. For a square step on the 2035 airliner at cruise conditions, the maximum height is 0.0196 in; for the rounded step the maximum height is 0.0294 in. Work on the smoothing layer should include a way to round the steps rather than have them be square in order to allow a slightly larger step height.

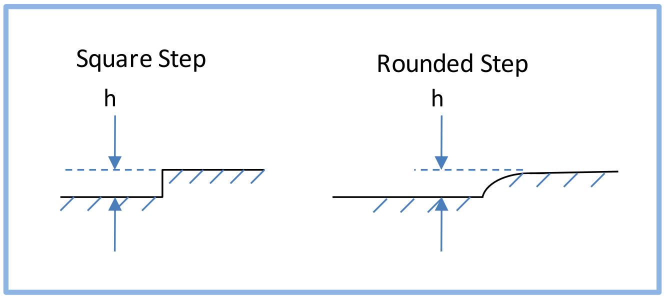


Figure 16: Reference geometry for steps.

5.2.3 Gaps

The empirical relationship for maximum gap width (as defined in Figure 17) is:

$$h < \frac{15{,}000}{R'}$$

For the 2035 airliner at cruise conditions, the maximum gap width is 0.163 inches. There are many opportunities for gaps in the areas where natural laminar flow is predicted (windscreen, windows, emergency escape hatch, nose landing gear door). Hybrid laminar flow (perhaps by providing some suction in select locations) may be necessary for the windscreen and nose landing gear door since those cannot be covered by a film and still operated. The windows and emergency escape hatch could potentially be covered by a film to minimize gaps.

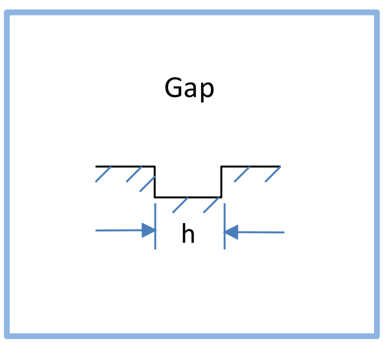


Figure 17: Reference geometry for gaps.

5.3 Conductivity

Conductivity (lightning strike) requirements fall into two categories: direct effects of lightning (DEL) and Indirect Effects of Lightning (IEL) or HIRF (High-Intensity Radiated Fields). The requirements for these two categories will be described in the following subsections.

5.3.1 Direct Effects of Lightning

The DEL strike requirement is defined in DO-160 Section 23 (Reference 6) as swept stroke for Zone 2A (100 k Amps). The aircraft requirement is that the aircraft be able to continue safe flight after a direct lightning strike (14CFR Part 25.581, 25.899, 25.981, and 25.954 from Reference 7). For structure, this means that the aircraft must maintain structural integrity when struck by lightning. Interpreted for protective skins, this requirement means that the protective skin must prevent structural damage to the primary structure, not that the protective skin must survive. Damage is measured by the size of the hole and amount of delamination on the outer and inner surfaces of the skin. DEL performance will have to be done outside Cessna.

5.3.2 IEL/HIRF

The requirement for IEL or HIRF protection (14CFR Part 25.13167) applies to electrical and electronic systems on the aircraft. The ability of the aircraft to meet this requirement is very dependent on many factors besides the skin of the aircraft. One of the primary factors is shielding. DO-160 does not provide requirements that decide pass/fail for shielding. Hence comparative studies are based on experimental data using a known material. The requirements for IEL/HIRF are to provide as much RF (radio frequency) shielding as carbon fiber composite (CFC) with ALS, both in low and high frequency ranges. This performance can be determined through a series of comparative tests performed in Cessna's Electromagnetic Effects Laboratory.

5.4 Cosmetic

One goal for the protective skins is to eliminate the need for aircraft paint and for the polished leading edges which are hallmarks of Cessna business jets. Another goal is for the cosmetic layer to include varying colors and designs which can be even more stunning than current aircraft paint schemes. Yet another goal is to combine at least the smoothing and cosmetic layer; with the right material adding lightning strike protection could be possible.

Like impact damage, the cosmetic requirements are a function of location, and locations which are visible have greater cosmetic requirements than those locations which are not easily observed (e.g., the wing undersides on a high wing aircraft and the side of fuselage have much more stringent cosmetic requirements than the top of the fuselage or wing and the bottom of most components.) There is also a potential difference between cosmetic expectations of business jet owners and passengers on a commercial airliner. The cosmetic requirements for this work will be more appropriate for a commercial airliner, allowing some flexibility in meeting those requirements. Finally, the smoothness requirements to facilitate natural laminar flow may overshadow what would otherwise be cosmetic requirements.

The list of cosmetic requirements includes at least the following items:

- No readily apparent rough edges
- No readily apparent dents or bumps
- No readily apparent cuts and scratches
- No readily apparent blushing (haze), bleeding, blistering, and water spotting

- No readily apparent shrink-down (patterns of the underlying materials are seen in the outer surface)
- No peeling
- Limited size and number of blemishes (defects from craters, dirt, and pin holes) (Reference 8)
- Consistent and even colors where intended; no color mismatch or readily apparent mottling
- No failure in accelerated weather resistance (Reference 9)
- No failure in outdoor weather resistance (Reference 9)

Typically gloss (the amount of specular reflection from the painted surface) is a requirement for paint. Rather than specifying a gloss level, the reflectivity requirement will be determined from a combination of the thermal protection requirement and visually appealing (a very subjective requirement).

5.5 Heat and Moisture

One of the key assumptions for viability of the STAR-C^2 protective skins is the ability to reduce the size and weight of the primary composite structure when the requirements to meet hot, wet conditions are eliminated. In an attempt to understand the potential magnitude of material knock downs for hot, wet requirements and to understand if one of the requirements is more important than the other, an analysis of composites data from the AGATE (Advanced General Aviation Technology Experiments) Program (Reference 10) was conducted. The results for the average of the unidirectional and plain weave composites are shown in Figure 18. In both cases, the knock down is slightly larger for wet but both wet and hot are around 20% knock down. The knock down for low temperatures is for load cases which do not drive sizing of the structure. The total knock down is just over 40% for unidirectional materials and just under 40% for plain weave composites.

The hot condition is related to skin temperature which is determined primarily by reflectivity while the wet condition is a function of the moisture in the atmosphere. In the following subsections requirements for reflectivity and moisture will be identified.

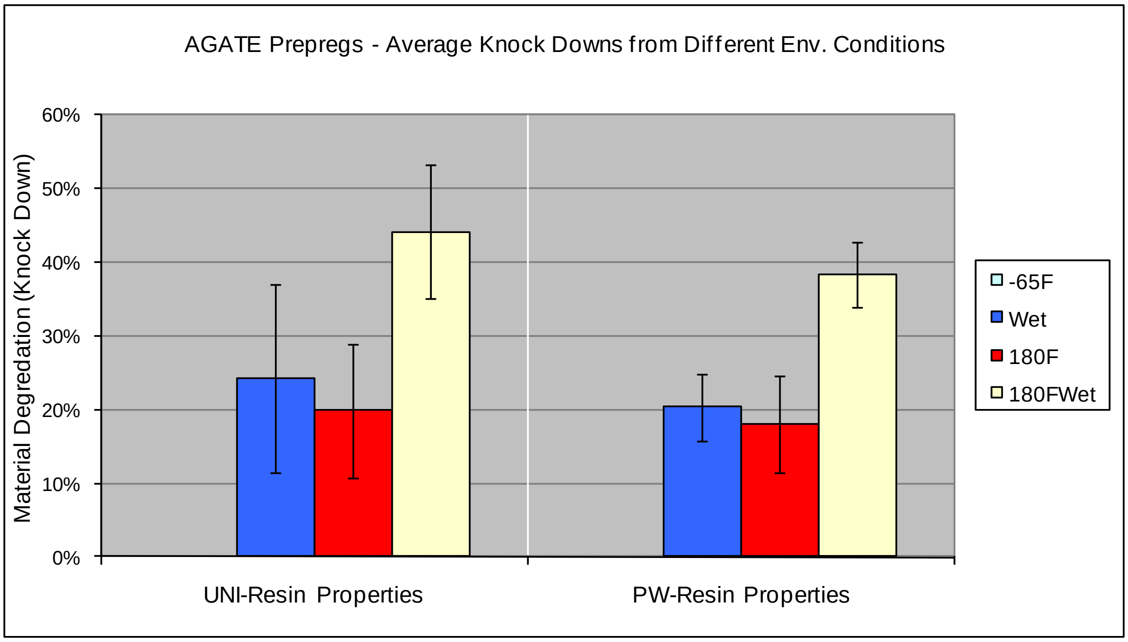


Figure 18: Average knock downs for AGATE prepregs from different environmental conditions (copied from Reference 10)

5.5.1 Reflectivity

The surface temperature of the skin is a function of the outer surface emissivity (ε) and outer surface absorptivity (α). As reported in Reference 11, the worst case condition is an airplane sitting on the ramp on a hot day with no wind. For a 105°F day with solar radiation intensity of 360 BTU/hr·ft^2 and no wind, a white painted surface (ε= 0.9, α=0.35) the outer surface temperature would be 130.3°F. For the same conditions with polished aluminum (ε= 0.04, α=0.0.30), the outer surface temperature would be 147.3°F. The relationship between solar absorption and emissivity is shown in Figure 19 (copied from Reference 12).

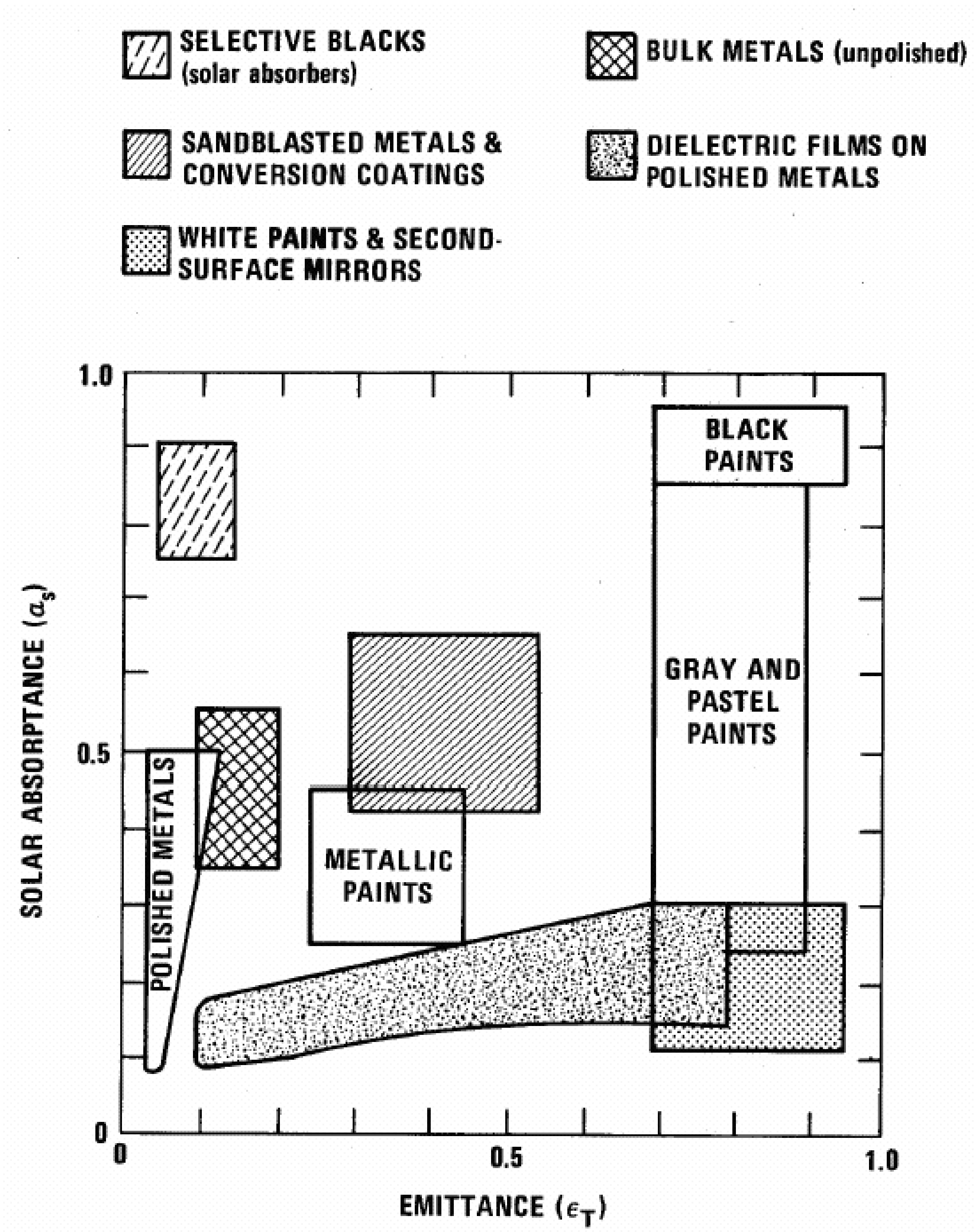


Figure 19: Absorptivity and emissivity characteristics of surfaces and coatings (copied from Reference 12).

Current composite primary structures are designed to withstand 180°F. The upper limit requirement for reflectivity for the STAR-C^2 protective skins is to find outer coverings with the correct emissivity and absorptivity to match the results for a white painted surface (temperature increase of 25°F). The target requirement is to find a material with emissivity and absorptivity which produce a surface temperature 15°F above ambient for this condition.

5.5.2 *Moisture*

While not part of the STAR-C^2 acronym, moisture is a consideration for the protective skins. With the elimination of the hot, wet requirement for the primary structure, the protective skins must serve as a moisture barrier. All of the skins and materials (film, shell, core, and adhesives) together must keep moisture out. In addition to the water absorption property of the materials, the transmission of moisture between gaps and seams between pieces of material must be minimized. One of the major concerns is knowing if and when the material has picked up moisture.

5.6 Thermal

The thermal requirement is strictly related to keeping the cabin comfortable. Thermal load on the cabin heat is composed of the electrical heat load, the solar direct heat load, the occupant heat load, the bleed air heat load (if present), the airframe conduction heat load, and vapor cycle cooling. Only the solar direct heat load and the airframe conduction load will be of interested for the STAR-C^2 protective skins. For upper to mid areas of the aircraft, the solar direct heat load is critical. For lower areas of the aircraft, the airframe conduction load will dominate.

Heat conduction through the structure of a traditional aluminum aircraft follows several paths. As described in Reference 11, a typical upper fuselage conduction path between the frames consists of the following layers of materials: 1) outer skin; 2) skin damping; 3) bagged fiberglass insulation; 4) nomex felt; and 5) interior panel. The conductive path over the frames consists of 1) outer skin; 2) fuselage frame; 3) Nomex felt; and 4) interior panel. The average overall heat transfer coefficient can be found using the ratio of the areas for each path.

The fuselage is divided into zones for analysis based on the types of materials in each area (e.g., windshield, window, door, cabin or cockpit sidewalls, etc.) and the likely heat loads (such as solar direct or airframe conduction). The temperature for thermal calculations when the aircraft is parked is either the outer fuselage skin temperature for zones with direct solar loading (from the mid-fuselage to the top of the aircraft) or, for zones containing the lower part of the fuselage (where airframe conduction load dominates), the temperature of note is the ambient air static temperature. Cessna designs primary structure for functionality between -67°F and +180°F.

For the STAR-C^2 protective skins, the cabin headliner will be a good representation of the direct solar heating case and the lower cabin sidewall of the fuselage conduction case. The overall heat transfer coefficient for a metallic Cessna business jet similar to the 2035 Advanced Airliner is 0.1300 BTU/hr·ft·°F (again from Reference 11) for the cabin headliner; it is 0.1344 BTU/hr·ft·°F for the lower cabin sidewall. The thermal requirement for the STAR-C^2 protective skins is an overall heat transfer coefficient similar to the aluminum airplane of 0.1300 BTU/hr·ft·°F for areas exposed to direct solar heating and 0.1344 BTU/hr·ft·°F for areas subject just to fuselage conduction. The goal of the STAR-C^2 skins will be to have the same heat transfer coefficients as an aluminum fuselage with internal insulation. Any area between the STAR-C^2 outside "shell" and the structural skin will help provide thermal protection. The thicker the area, the better it will protect the structural skin from solar heat.

5.7 Acoustic

Acoustic treatment is used inside current fuselages to reduce the noise level in the cabin. The 2035 20-passenger airliner uses the General Electric Year 2030-2035 Ultra Quiet and Efficient Turboprop

(UQETP) concept (Reference 1). Extensive effort was made to evaluate the external (community) noise for the Phase 1 effort. There was no NASA requirement for interior noise evaluation, and no estimated data was presented on interior noise. Natural laminar flow over approximately half of the fuselage should help reduce the interior cabin noise compared to an airliner with turbulent flow. Additionally, the UQETP does use "an efficient, noise-optimized propeller with advanced, low emissions turbo machinery and a performance- and quiet-enhancing control system (Reference 1)." Relatively low cruise speed (M=0.55 at 39,000 ft) results in a relatively low propeller tip speed (590 ft/sec) at cruise. The propeller has eight blades, a moderate 105 activity factor, and a diameter of 9.84 feet.

Given the lack of specific information on the noise characteristics of the UQETP, the acoustic requirement inside the cabin is that the transmission loss (TL) should be the same (within 2 dB) or better than damped aluminum at frequencies below 3000 Hertz. The interior noise goal is 80-90 dBA.

5.8 Environmental Considerations

The applicable requirements include temperature, fluids susceptibility, and salt fog. STAR-C^2 skins will not be tested for these considerations; rather the considerations will be used to guide the selection of materials. These requirements will be defined in the following subsections.

5.8.1 Temperature

As already described in the section on thermal requirements, composite structures at Cessna are designed for the temperature range from -67°F to +180°F. This will be the requirement for the temperature operability range for the STAR-C^2 protective skins.

5.8.2 Fluids Susceptibility

The protective skins shall tolerate the following aviation fluids with no adverse effects per DO-160G6 Section 11.0 (Category F): aviation Jet A fuel, mineral-based hydraulic fluid, phosphate ester-based (synthetic) Type IV hydraulic fluid, isopropyl alcohol cleaner, cleaning compound for aircraft surfaces, and ethylene glycol de-icing fluid.

5.8.3 Salt Fog

The protective skins shall withstand the DO-160G6 Section 14.0 Category S salt fog requirement. Category S is subject to a corrosive atmosphere in the course of normal aircraft operation.

5.9 Additional Considerations

These final additional considerations impact the ease of installation and repair along with how long the skins last. Trades will be required between reparability and durability to determine the most optimum skin configuration.

5.9.1 Conformability

The STAR-C^2 protective skins (especially the outer skin) should be conformable, meaning that the skin assumes the shape of the surface to which it is applied without cracking or breaking and without the

formation of any bubbles or wrinkles. Reference 13 suggests testing which can be conducted to demonstrate conformability.

5.9.2 Reparability

One major requirement for the STAR-C2 protective skins is that they make any meaningful damage visible. Once made visible, repairs to the skins should be reasonable to accomplish. Ideally, cutting out the damaged area, replacing it, and taking some action to smooth the skin would accomplish a repair. However, the outer skin may be sufficiently delicate that the most efficient repair is to remove the entire outer film, repair the core material, and replace the entire outer film with a new one. Cost and ease of installation would need to be positive characteristics of the outer skin for this to be viable.

5.9.3 Durability

The normal desire would be for materials which last for the life of the aircraft. However, trades will be necessary between appearance, degradation in performance with time, weight, cost to replace, and cost to repair. If the protective skins are inexpensive and relatively easy to replace, it may be most effective to replace them rather than to require that the cosmetic appearance stay nearly perfect.

Additionally, previous work suggests that adhesive-backed films, applied to the flow control surfaces in order to maintain a smooth, protected surface for drag reduction, tend to perform poorly and are unsuitable for areas of high erosion such as wing and tail leading edges and nacelle inlets (Reference 13). Presumably, these materials would also be subject to erosion on the nose of the fuselage, an important consideration for these protective skins since much of the natural laminar flow benefit is achieved on the forward part of the fuselage. Erosion is an important consideration for the outer layer of skin.

6 Materials

The initial STAR-C2 protective skin concept consisted of two layers (as was shown in Figure 5 and is repeated here in Figure 20). The core foam is expected to meet the impact, thermal, and acoustic requirements while the film is expected to meet the smoothing, lightning strike, cosmetic and moisture barrier requirements. Materials searches were conducted to find the commercially available potential materials which could be used to produce the protective skins.

Databases of potential core and film materials were created from a wide-ranging Internet search. Little regard was given to specific design use for this initial gathering. Separate lists of characteristics were developed for the core and film materials. The lists of characteristics were developed based on every parameter imaginable which could possibly be of use or interest. The databases were populated using the available manufacturers' supplied data. The following subsections will present the data characteristics sought and the materials identified for the core and film materials.

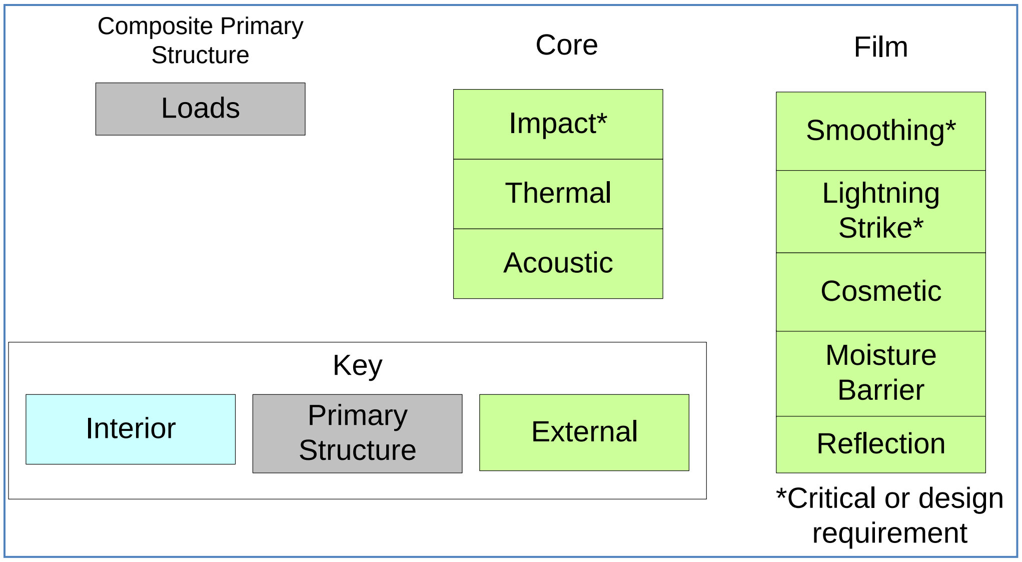


Figure 20: Functional arrangement for primary composite structure.

Absence of data was a major problem. Differing units of measure and test methodologies were other problems which made it challenging to align the data in a format to support further review. Cost was not available for any of the materials. The selected approach to materials selection was to use the publicly available data from the Internet search to down select to a smaller set of materials which were investigated in greater depth with manufacturers and suppliers.

6.1 Impact Absorbing/Spreading

As shown in Table 8, there were 42 unique characteristics sought for the core materials. The search resulted in 163 potential core materials (many of which were variations of the same material with slightly different characteristics) which are shown in

Table 9.

Table 8 - Core Materials Properties Sought

Material Type	
Manufacture	
Product #	
Application	
Density Range (lbs/ft^3)	MINIMUM
	MAXIMUM
Sheet size (in)	Length
	Width
Temperature Deg F	Continues
	Process
	Tg
Open or Closed Cell	
Chemical Resistant (Yes/No)	
Resin Absorption	
Thermal conductivity (BTU/(hr*ft*°F)	
Electrical Conductivity (Siemens)	
Acoustic Damping	
Water absorption(lbs/ft2)	
Hydroscopic (Yes/No)	
Flame, Smoke, Toxicity	
CTE (mean) x10-5 in/in/F	
lbs/ft^3	
Compression Strength	Parallel
	Perpendicular
Compression Modulus	Parallel
	Perpendicular
Shear Strength	Parallel(width)
	Perpendicular / parallel(thick)
Shear Modulus	Parallel(width)
	Perpendicular / parallel(thick)
Tensile Strength	Parallel
	Perpendicular
Tensile Modulus	Parallel
	Perpendicular
Flexural Strength	Parallel
	Perpendicular
Flexural Modulus	Parallel
	Perpendicular
Compression Strength (250F)	Parallel
	Perpendicular
Compression Modulus (250F)	Parallel
	Perpendicular

Table 9 - Core Material List (1 of 3)

Material Type	Manufacture	Product #		Application
Polyurethane	Last-A-Foam	FR-3700		Tooling
Polyurethane	Last-A-Foam	FR-4300		Cushion
Polyurethane	Last-A-Foam	FR-4500		Tooling
Polyurethane	Last-A-Foam	FR-6700		Structural
Polyurethane	Last-A-Foam	FR-7100		Tooling
Polyurethane	Last-A-Foam	FR-10100		Structural
Polyurethane	Last-A-Foam	FR-10700		Tooling
Polyurethane	Last-A-Foam	TR Foam		Marine
Styrofoam	DOW	STYROFOAM RTM		REFRIGERATED TRANSPORT
Styrofoam	DOW	STYROFOAM HD300		COLDSTORAGE
Styrofoam	DOW	STYROFOAM LB		COMPOSITE PANELS
Styrofoam	DOW	STYROFOAM LT		COLDSTORAGE
Styrofoam	DOW	STYROFOAM SP		COLDSTORAGE
Polystyrene	Boedeker Plastics	Expanded polystyrene		General Purpose Polystyrene (GPPS)
Polystyrene	Boedeker Plastics	Expanded polystyrene		High Impact Polystyrene (HIPS)
Polyurethane	Rigid Polyurethane Foam			
Polyurethane	PUR izolace s.r.o.			
Polyurethane- Fiber reinforced				
Polymer	Divinycell	Divinycell H35 Grade		Sandwich Composite
Polymer	Divinycell	Divinycell H45 Grade		Sandwich Composite
Polymer	Divinycell	Divinycell HP60 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP80 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP100 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP130 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP160 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP200 Grade		Marine, Wind Energy, Transportation and Industrial Markets
Polymer	Divinycell	Divinycell HP250 Grade		Marine, Wind Energy, Transportation and Industrial Markets

Table 9 - Core Material List (2 of 3)

Material Type	Manufacture	Product #		Application
Polymer	Divinycell	Divinycell F50 Grade		Aircraft Interiors
Polymer	Divinycell	Divinycell F90 Grade		Aircraft Interiors
Polymer	Divinycell	Divinycell F130 Grade		Aircraft Interiors
Polymer	Divinycell	Divinycell P60 Grade		Public Transportation, Industrial and Wind Energy
Polymer	Divinycell	Divinycell P100 Grade		Public Transportation, Industrial and Wind Energy
Polymer	Divinycell	Divinycell P120 Grade		Public Transportation, Industrial and Wind Energy
Polymer	Divinycell	Divinycell P150 Grade		Public Transportation, Industrial and Wind Energy
Polymer	Divinycell	Divinycell HT60 Grade		Aerospace
Polymer	Divinycell	Divinycell HT80 Grade		Aerospace
Polymer	Divinycell	Divinycell HT100 Grade		Aerospace
Polymer	Divinycell	Divinycell HT130 Grade		Aerospace
Polymer	Divinycell	Divinycell HCP30 Grade		High Density Core for Sub-Sea buoyancy
Polymer	Divinycell	Divinycell HCP50 Grade		High Density Core for Sub-Sea buoyancy
Polymer	Divinycell	Divinycell HCP70 Grade		High Density Core for Sub-Sea buoyancy
Polymer	Divinycell	Divinycell HCP90 Grade		High Density Core for Sub-Sea buoyancy
Polymer	Divinycell	Divinycell HCP100 Grade		High Density Core for Sub-Sea buoyancy
Linear PVC	Core Composite			Thermoformable
Linear PVC	Core Composite			Thermoformable
X-Linked PVC	Core Composite			Structural core like marine hulls, decks, wind turbine blades
Polyethylene terephthalate	3A COMPOSITES CORE MATERIALS	Airex-t92.100		windenergy,marine,industrial
Polyethylene terephthalate	3A COMPOSITES CORE MATERIALS	Airex-t92.110		windenergy,marine,industrial
Polyethylene terephthalate	3A COMPOSITES CORE MATERIALS	Airex-t92.130		windenergy,marine,industrial
Polyethylene terephthalate	3A COMPOSITES CORE MATERIALS	Airex-t92.200		windenergy,marine,industrial
Polyethylene terephthalate	Boedeker Plastics, Inc.	Ertalyte		Fuel pump components
Airex-C70	3A COMPOSITES CORE MATERIALS	Airex-C70.4		Aerospace cockpit,fuselage
Airex-C71	3A COMPOSITES CORE MATERIALS	Airex-C71.55		Interiors, radomes, galley carts, general aviation (sport aircraft)
Airex-R82	3A COMPOSITES CORE MATERIALS	Airex-R82.6		Interiors, cockpit doors, cryogenic tanks, insulating panels, radomes,

Table 9 - Core Material List (3 of 3)

Material Type	Manufacture	Product #		Application
Balsa wood	3A COMPOSITES CORE MATERIALS	BALTEK SB 50		Aerospace
Balsa wood	3A COMPOSITES CORE MATERIALS	BALTEK SB100		Aerospace
Balsa wood	3A COMPOSITES CORE MATERIALS	BALTEK SB150		Aerospace
Balsa	Core Composites	End Grain Balsa CD 5		Marine
Balsa wood	Diab products	Pro Balsa LD7 light WEIGHT		Aerospace
Honeycomb plastic	Nida Core	H11PP-45		windenergy,marine,industrial
Honeycomb- paper	Core Composites	Nomex		Aircraft Interiors
Honeycomb- paper	Core Composites	Nomex		Aircraft Interiors
Honeycomb-filled				
Honeycomb-FibreGlass	Ultracore	UGF-250F-3/8 -2.5		Aerospace
Honeycomb-FibreGlass	Ultracore	UGF-256F-1/4 -4		Aerospace
Honeycomb- Metallic	Core Composites	Aluminium		Marine Structures
Honeycomb- Metallic	Core Composites	Aluminium		Marine Structures
Lantor Soric	Lantor Composites	Lantor Soric SF 2		windenergy,marine,industrial
Lantor Coremat	Lantor Composites	Lantor Coremat Xi		windenergy,marine,industrial
Other				
Innegra S	Innegrity	Innegra S		Police and military vests and helmets, composite arnor for aircraft and vehicles, aerospace structures
Tegris (polypropylene)	Milliken & Company	Tegris sheet		Anti-Ballistics,Transportation,Sports and Leisure,Watersports
Solimide	Evonik industries	AC530 Polymide		Aerospace
Solimide	Evonik industries	AC550 Polymide		Aerospace
Polymide	GFT LLC	Performa-H		
IMPAXX Foam	Dow	IMPAXX 300 Energy Absorbing Foam		Variety of industries requiring enhanced safety features through energy absorbing coutnermeasures.
IMPAXX Foam	Dow	IMPAXX 700 Energy Absorbing Foam		Variety of industries requiring enhanced safety features through energy absorbing coutnermeasures.
Polydamp Hydrophobic Melamine Foam	Polymer Technologies Inc.	Polydamp Hydrophobic Melamine foam (PHM)		HVAC and ECS ducts, wall/fuselage insulation in aircraft, mass transit, etc.

Impact damage was selected as the initial characteristic to investigate. Foam core crush strengths (compression) range from 36 psi on 1.7 pcf Styrofoam to 5,732 psi on 50 pcf Last-A-Foam FR 4500.

Honeycomb crush strengths range from 95 psi on 1.5 pcf Honeycomb Nomex to 2900 psi on 12 pcf Honeycomb Aluminum. Figure 21 clearly shows that honeycomb has greater strength at lower densities than foam. For a given required compression strength, a foam core would need to have approximately three times the density in order to match the compression strength.

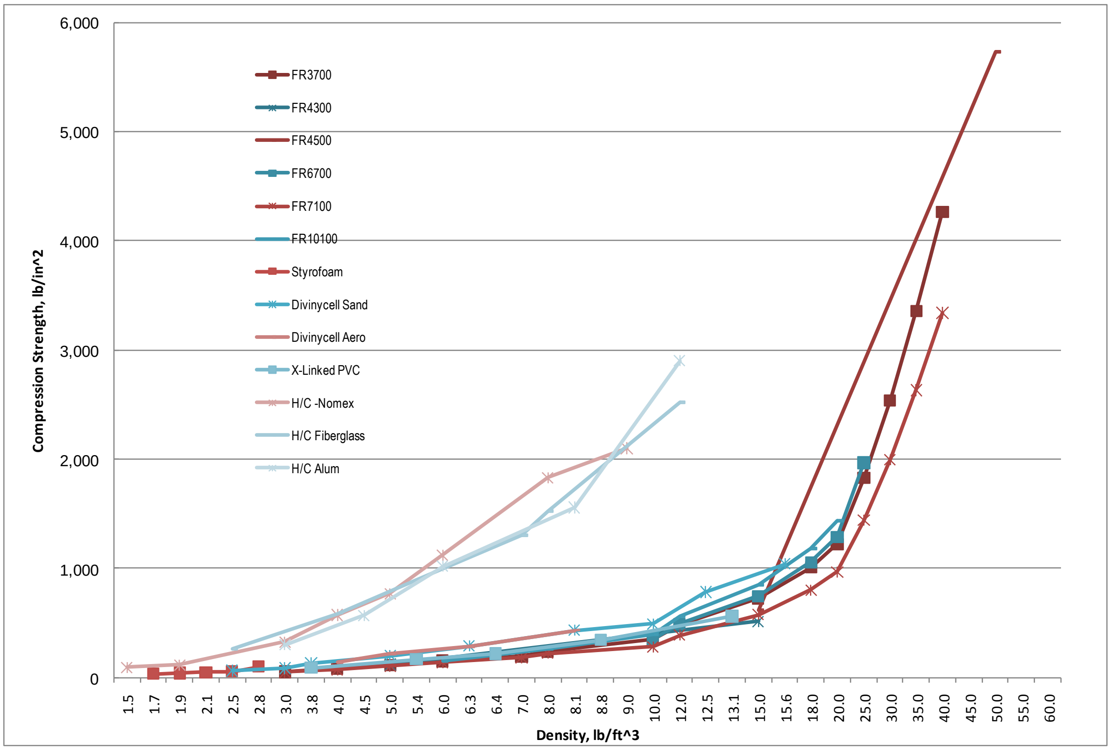


Figure 21: Compression strength as a function of density for foam and honeycomb core materials.

Compression strength is key to impact damage calculations. A core thickness prediction which meets the impact energy requirement can be made based on the compression modulus of the materials. The following assumptions were made in order to make the calculation. The load is assumed to increase linearly until crushing is initiated. The load is then considered to be constant until core failure. Failure is predicted at 50% of the core total design thickness. The requirement for impact is a standard load of 3.0 lbs dropped from a height of 60 in yielding an impact of 180 inch-lbs. An impact diameter of 1.0 in^2 was used.

The results of the calculations are shown in Figure 22**.** To keep the core thickness at 0.4 in, the aluminum honeycomb would require 6.0 lb/ft^3 density core as compared to the foam cores requiring 15-30 lb/ft^3. For this figure, the core material thickness was limited to 2.0". The goal for the thickness metric set out earlier was a maximum thickness of 1.0 in and a target of 0.25 in. At total thickness of the core layer of 0.20" would require a 12 lb/ft^3 honeycomb core or between 30-35 lb/ft^3 foam core, with a possibility of up to 45 lb/ft^3 FR 4500 Last-A-Foam. This result allows elimination of over 50% of the database, including any honeycomb less than 6.0 lb/ft^3 and foam under 10 lb/ft^3.

Based on these results any one of the honeycomb core materials would be a good choice for impact absorption ability. Honeycomb will present extra challenges compared to foam with manufacturability and repair. Stiffness of the honeycomb will make draping the material around complex curvatures

difficult, and obtaining smooth seams and small gaps when joining panels together or making repairs will require research. Foam would be a much better solution for these issues. However, the significantly higher densities and thicknesses required by foam materials would quickly eliminate the lighter weight and increase the drag more than it is reduced by natural laminar flow.

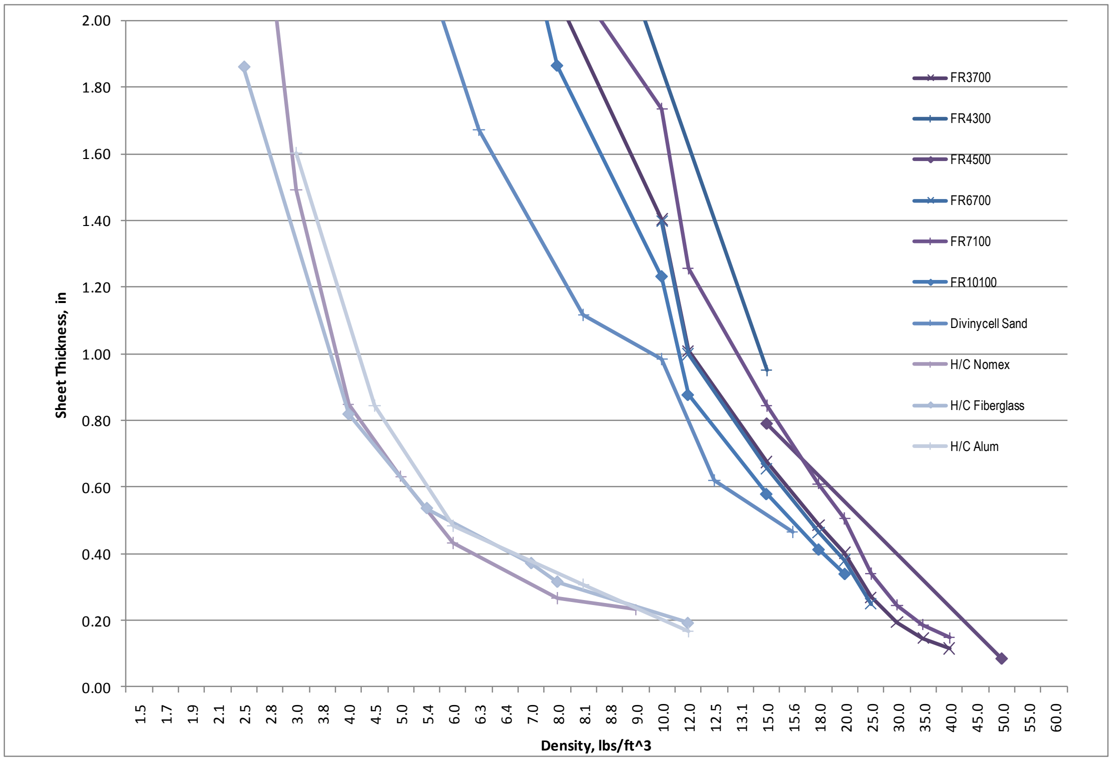


Figure 22: Required sheet thickness for honeycomb and foam core materials.

The core thickness calculations used an impact area of 1.0 in^2. Given that the thicknesses of required core materials were larger than desired, a study was conducted on the effect of impact area. The 4.5 pcf aluminum honeycomb compression strength and modulus were used for the study; results are shown in Figure 23. Increasing the impact area has a large effect on the decrease in required core thickness. There are at least two ways to increase the impact area: 1) use a larger impactor (not practical since in actual use the size of objects impacting the aircraft is not controllable); or 2) put a structurally stiffer or “hard” shell over the core to spread the impact load over a wider area. The hard shell concept is widely used and can easily be seen in the helmets used by race car drivers, motorcyclists, and other numerous sporting activities where crash protection is critical.

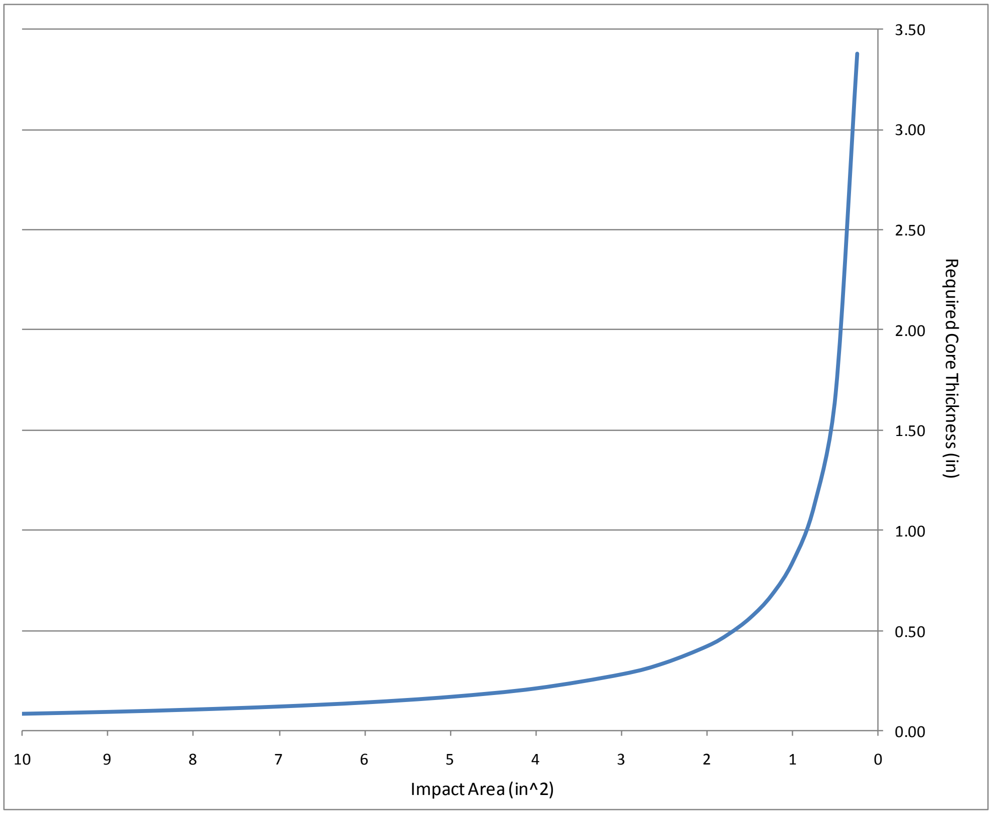


Figure 23: Required core thickness for varying impactor sizes.

The protective skin functional diagram, modified to include a shell layer, is shown in Figure 24**.** In addition to spreading the load, the shell could also potentially serve as the moisture barrier. With this concept, the number of layers for the protective skins would go from two to three. There is a possibility, although remote, that a material could be found which could meet both the shell and the film functions. The most likely STAR-C^2 protective skin will have at least three layers.

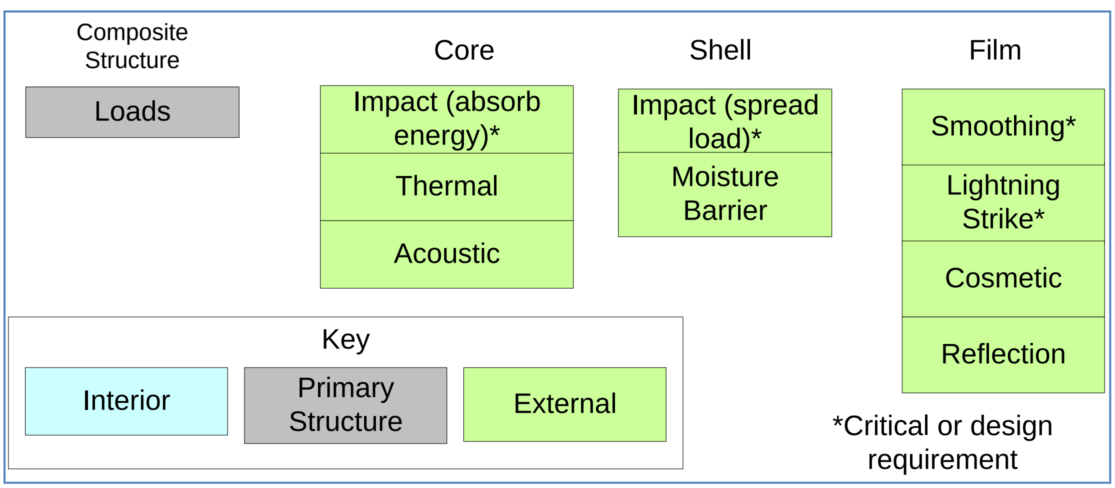


Figure 24: Functional arrangement for protective skins with three layers.

6.2 Conductive Films

The 32 unique characteristics sought for the film materials are shown in Table 10. While there are many similarities between the core and film characteristics, there are also some key differences. While the core materials focus on strengths, the film materials focus more on electrical conductivity and color.

There are 44 film materials in the database as shown in Table 11. The search for these materials was frustrating in that there were so many options. The options for films which can be printed appear to be nearly unlimited. However, the options for films which can be printed, look good, withstand the flight environment, provide lightning protection, and provide adequate reflection to keep the primary composite structure skin temperature low are difficult to uncover, partly due to lack of comprehensive and consistent data. More work is needed with specific vendors to look for options that will work.

6.2.1 Smoothness

Laminar flow is a strong function of smoothness. Critical issues for the STAR-C^2 skins are related to the joining/sectioning of the panels and around windows, doors, etc. The film materials should be thick enough to reduce the criticality of these joints. Having the capability to provide rounded steps is also a desirable property of the films.

6.2.2 Lightning Strike

The traditional method of protecting composite structures for lightning strike is to add a layer of expanded metal (usually aluminum or copper) foil. The lightest weight foils usually provide adequate protection over areas at least 12 in wide (Reference 14); heavier weight foils need to be applied to narrow strips. Expanded aluminum mesh weighing 0.016 lb/ft^2 provides 8-12 kA/inch of current density capability. For comparison, 0.028 lb/ft^2 copper expanded mesh provides 7 kA/inch. Solid aluminum 0.0001 in thick provides 8 kA/in, 0.002 in thick provides 14 kA/in, 0.003 in thick provides 20 kA/in, and 0.006 in thick provides 35 kA/in. Application of solid foil is not desirable because it is difficult to drape, difficult to fit over complex geometries, and difficult to bond. There is a weight penalty for traditional lightning protection. Expanded aluminum foil weighs about 1.6 lbs/100 ft^2, interwoven aluminum wire about 0.024 lbs/100 ft^2, solid aluminum foil about 8.5 lbs/100 ft^2, aluminum thermal spray 5.75 to 8 lbs/ft^2, and silver conductive paint about 8 lbs/100 ft^2. The goal for lightning strike protection for the STAR-C^2 skins is to a material which has current density capability of 8-12 kA/in.

6.2.3 Cosmetic

Cosmetic concerns include the material being a reasonable overall color and being able to be colored in local areas by printing. Development of initial data base used screening for printing ability so materials which cannot be decorated by printing are not included.

6.2.4 Reflection

The proper reflectivity of the film material is crucial to maintaining moderate temperatures of the primary structure. There are very impressive window films (many made by 3M) which have 99.99% ultra violet (UV) rejection and 97% infrared (IR) rejection.

Table 10 - Film Materials Properties Sought

Material Type	
Manufacture	
Product #	
Application	
Density (lb/ft^3)	
Thickness (in)	Low (in)
	High (in)
Brittleness	
Heat Deflection Temperature	
Tg	
Color	
Chemical- resistant	
Water Absorption (%, 24 hrs)	
Thermal conductivity (Btu/hr/ft^2/deg F/in)	
Thermal Expansion (x10-5/deg F)	
Flammability	HWI(in)
	HAI(in)
CTE (mean) x10-5 in/in/F	
lbs/ft^3	
Tear Strength	Puncture Resistance (ft-lb)
	Initiation (lb/mil)
	Propogation (lb/mil)
Tensile (psi)	Strength (MAX)
	Modulus
Diaelectric Strength	
Dielectric Constant (ASTM D150 @60Hz)	
Dielectric Constant (ASTM D150 @1M Hz)	
Dissipation factor (ASTM D150 @ 60Hz)	
Dissipation factor (ASTM D150 @ 1M Hz)	
Volume Resistivity (Ω-cm)	
Surface Resistivity (Ω-square)	
Costs	

Table 11- Film Materials (1 of 2)

Material Type	Manufacture	Product #	Application
Polycarbornate	LEXAN	FR25A	General use
Polycarbornate	curbellplastics	DE 1-1 gloss/gloss	General use
Polycarbornate	curbellplastics	Polycarbo te Film PCVM Velvet/Matte	General use
Polyester	curbellplastics	SH71S	mechanical and dielectric strength
Polyester	The Gund Company, Inc.	Melinex Polyester Film Type 226	electrical insulation
Questa polyester polyethylene terephthlate	Filmquest	--	electrical insulation,industries
Acrylic Polymer	DOW	Rhoplex EC-1791	Roof Coating
Epoxy Film	3M	Super 10	Electrical Tape
Polyimide	DuPont Kapton	HN	
Polyimide	DuPont Kapton	500HN	
Polyimide	DuPont Kapton	300MTB	
Polyimide	DuPont Kapton	500MTB	
Polyimide	DuPont ™ Cirlex ®	900CL	
Polyimide	DuPont ™ Cirlex ®	1200CL	
Polyimide	DuPont ™ Cirlex ®	1500CL	
Polyimide	DuPont ™ Cirlex ®	3000CL	
Polyimide	DuPont ™ Cirlex ®	5000CL	
Polyimide	Boedeker	Imidex	
Thin Fluoropolymer	Welch Fluorocarbon	Modified PTFE (polytetrafluoroethylene)	
Thin Fluoropolymer	Welch Fluorocarbon	PFA(perfluoroalkoxy)	
Thin Fluoropolymer	Welch Fluorocarbon	FEP(fluoroethylene-propylene)	
Thin Fluoropolymer	Welch Fluorocarbon	ETFE(ethylene-tetrafluoroethylene-copolymer)	
Thin Fluoropolymer	Welch Fluorocarbon(Halar®)	ECTFE(ethylene-chlorotrifluoroethylene)	
Thin Fluoropolymer	Welch Fluorocarbon	PVF(polyvinyl-fluoride)	
Thin Fluoropolymer	Welch Fluorocarbon(Aclar® & Clarus®)	PCTFE(polychloro-trifluoroethylene)	
Tempalux	Westlake Plastics	polyetherimide(PEI)	High temperature labels,Electrical insulation,Hot melt adhesives
Thermalux	Westlake Plastics	polysulfone	electronics,medical devices, chemical process equipment and automotive industries

Table 11 - Film Materials (2 of 2)

Material Type	Manufacture	Product #	Application
Tedlar(polyvinyl fluoride film)	Dupont	TTR5JAM9	gas sampling,sound-absorbing ceiling tiles
Fluoropolymer film	Saint-Gobain Advanced Films	Norton® ECTFE	electrical tapes, cable insulation, printed circuits, capacitors
Thermoplastic Polyurethane Films	Kerafol	Keratherm – MT 102	Flexible ceramic heat conducting and isolating tape
Thermoplastic Polyurethane Films	Kerafol	Keratherm – MT 103	Flexible ceramic heat conducting and isolating tape
Silicone Elastomer	Kerafol	Keratherm White 86/30	Power supplies White goods Audio and video Components Engine controllers Power converters
Silicone Elastomer	Kerafol	Keratherm Green 86/37	Automotive Telecommunication units DC-DC converters High voltage units
Silicone Elastomer	Kerafol	Keratherm Pink 86/50	Automotive White goods Engine controllers Audio and video Components LCD displays Power converters
Silicone Elastomer	Kerafol	Keratherm Red 86/81	High end thermal solutions Hard disc drives Controlling boards BGA applications
Silicone Elastomer	Kerafol	Keratherm Red 86/82 (w/fiberglass)	High end thermal solutions Hard disc drives Controlling boards BGA applications
Silicone Elastomer	Kerafol	Keratherm Red 86/83 (w/fiberglass)	High end thermal solutions Hard disc drives Controlling boards BGA applications
Silicone Elastomer	Kerafol	Keratherm Brown 70/50 w/fiberglass	Automotive White goods Engine controllers Audio and video Components LCD displays Power converters
PCE Films	Kerafol	Keratherm – 86/114	Flexible heat conducting and Isolating tape
PCE Films	Kerafol	Keratherm – 86/117	Flexible heat conducting and Isolating tape
Fluorogrip polymer film(ethylene-chlorotrifluoroethylene)	Integument Technologies, Inc.	LS-1000	constructing structures that are susceptible to lightning strikes
FluoroGrip Optically Clear Film	Integument Technologies, Inc.	F Optically Clear (HD-FEP) Teflon	to protect standard polycarbonate glass used on equipment such as critical clean and etch, post-ash clean/photoresist strip
FluoroGrip® – E fluoropolymer	Integument Technologies, Inc.	E (ECTFE) Halar	tanks,and hoppers,pipe wraps, anti-graffiti, paint replacement, splash and spill protection and exterior corrosion protection of steel, concrete, fiberglass and other plastic structures and equipment
FluoroGrip® – MFA	Integument Technologies, Inc.	TFE/perfluoromethylvinylether	tank linings,splash-and-spill environments,UV protection

7 First-Generation Test Articles

During the program, two generations of test articles were constructed and tested. The first-generation test articles consisted of a wide variety of materials and thicknesses of materials. The materials were selected partially based on investigator familiarity and partially based on availability within the project timeframe. This was the first time many of these materials had been combined. Cessna standard resins and adhesives were used without significant consideration for the integration of the materials. The testing could be regarded as screening tests. The goal of the first generation of test articles was to validate material thoughts and provide direction on a much more focused second generation of test articles. The Section 7 subsections describe the first generation of test articles and the testing, with final thoughts on the material composition for the second generation of test articles.

7.1 Test Articles

The most promising materials were selected for impact spreading, impact absorbing, lightning strike protection, and aesthetics and smoothing. The materials are identified and described in Section 7.1.1. Links to manufacturer websites with information about the materials are presented in Appendix A – Links to Information about Materials Used. These materials were combined into 173 test articles. The test article composition and geometry will be presented in Section 7.1.2.

7.1.1 Material Definition

The materials used in the test articles are shown in the following five tables. Table 12 shows the energy (impact) absorbing materials used in the test articles. There are three volumetric densities of polyurethane core, one non-metallic honeycomb (used for aesthetics and smoothing), three volumetric densities of metallic honeycomb (while 9 pcf was desired, the supplier could only get 7.9 pcf in the timeframe available to build the panels), two different types of Soric with three thicknesses, and one Polydamp hydrophobic melamine foam with metalized PEEK skin.

Table 13 shows the materials used for the impact spreading layer. The Innegra S and Tegris LM were of serious interest. The carbon epoxy was used to determine the performance of a known material which is also known to be heavy. The aluminum sheet was used for comparison because it would produce definite permanent damage.

Table 12 - Energy Absorbing Materials

Material Trade Name	Material Composition
10 pcf polyurethane core, FR-6710	Polyurethane
20 pcf polyurethane core, FR-6720	Polyurethane
30 pcf polyurethane core, FR-3730	Polyurethane
4 pcf non-metallic (Nomex 1/8” cell) honeycomb core	Nomex honeycomb
3 pcf metallic honeycomb core (1/4” cell, 5052 aluminum, 0.0015” thick wall, nominally 3.4 pcf)	Aluminum honeycomb
6 pcf metallic honeycomb core (1/4” cell, 5052 aluminum, 0.003” thick wall, nominally 6.0 pcf)	Aluminum honeycomb
7.9 pcf metallic honeycomb core (1/4” cell, 5052 aluminum, 0.004” thick wall, nominally 7.9 pcf)	Aluminum honeycomb
Soric LRC – Low Resin Content (2 and 3 mm)	Polyester nonwoven with compression resistant hexagonal cell structure containing synthetic micro-spheres
Soric XF (2 and 6 mm)	Polyester nonwoven with compression resistant hexagonal cell structure containing synthetic micro-spheres
Polydamp hydrophobic melamine with metalized PEEK skin on one side and pressure sensitive adhesive on the other side	Melamine foam with metalized polyether ether ketone thermoplastic skin on the outer facing side of the foam and with pressure sensitive adhesive on the inner facing side of the foam

Table 13 - Impact Spreading Layer Materials

Material Trade Name	Material Composition
Innegra S plain weave	Polypropylene
Tegris LM plain weave	Polypropylene
Carbon epoxy	Besfight G30-500 3K tow 8 harness satin weave
Aluminum alloy sheet (0.012”)	Aluminum

The lightning strike protection materials are shown in Table 14. The 0.016 psf expanded aluminum foil and 0.029 psf expanded copper foil are current standard lightning strike materials. The Integument with lightning strike protection was a premade combination of Integument film and traditional aluminum foil lightning strike protection. The LDS 50-01 0.007 is a new (to Cessna) very light and very fragile aluminum foil (it greatly resembles a gum foil wrapper). The proprietary spray and Nanocomp Technologies carbon nanotube materials were special materials which were included to represent newer technology materials. The proprietary spray material was heavy and did not perform particularly well on direct lightning strikes. The carbon nanotube materials did not fit within the target material cost per square foot.

Table 15 describes the five aesthetic layer materials. Three of the materials (Integument, 3M 5004, and Aptiv PEEK) came with pressure sensitive adhesive. The 3M F9460PC transfer tape (presented in

Table 16) was used for the Halar and Kapton to adhere the films to the lightning strike protection layers. No special treatments were requested on the adhesive side of the films to aid adhesion.

Table 14 - Lightning Strike Protection Materials

Material Trade Name	Material Composition
0.016 psf expanded aluminum foil	Aluminum
Integument with lightning strike protection and pressure sensitive adhesive	Fluorogrip polymer film (ethylene-chlorotrifluoroethylene) with 0.016 psf expanded aluminum foil
0.029 psf expanded copper foil	Copper
LDS 50-01 0.007 psf aluminum	Aluminum
Proprietary Spray Material	Proprietary Spray Material
Nanocomp 11 and 15 gsm carbon nanotube sheets	Carbon nanotubes

Table 15 - Aesthetic Layer Materials

Material Trade Name	Material Composition
Integument film with pressure sensitive adhesive	Fluorogrip polymer film (ethylene-chlorotrifluoroethylene)
3M 5004 with pressure sensitive adhesive	Fluoropolymer film with acrylic adhesive
Halar	Ethylene-chlorotrifluoroethylene
Aptiv PEEK with pressure sensitive adhesive	Polyaryletherketone in a flexible film format
Kapton	Polyimide

Table 16 - Interface Layers Material Definition

Material Trade Name	Material Composition
3M 4950 Very High Bond Double-Sided Foam Tape (45 mil thick)	Viscoelastic acrylic foam
Aeropoxy PR2032 and hardener PH3660	Multifunctional acrylate resin and modified amine mixture with diphenylolpropane hardener
Grade 30 film adhesive	FM 73C fracture-tough modified epoxy-nitrile structural film
3M F9460PC transfer tape (2.0 mil thick)	3M 100MP acrylic adhesive

The interface layers material definitions are presented in Table 16. All of the test articles had 3M 4950 Very High Bond (VHB) double-sided foam tape on the back side of the protective skin to attach the protective skin to the base substrate panel. Protective backings were not removed from the 3M 4950 tape for most of the impact test articles so that the base substrate panels could be inspected from the top side. The Aeropoxy resin system was used to bond the foam cores and Soric. The Grade 30 film adhesive was used over the top of honeycomb to provide an adhesive surface without allowing resin to fill the cells of the honeycomb which would greatly increase the weight. And finally, as previously mentioned in this section, the 3M F9460PC transfer tape was used to adhere the Halar and Kapton aesthetic films to the lightning strike material.

7.1.2 Drawings

Table 17 shows the combinations of materials used in the impact panels; Figure 25 shows a sample drawing for the impact panels. Each panel was 24” by 24”, and all of the layers extended the full 24” by 24.” The impact panels do not have lightning strike protection or aesthetic film; they do have the impact absorbing and impact spreading layers in all but one case – for panel IM-100, the material is a combination impact protecting/spreading layer combined.

The combinations of materials used in the lightning strike panels is shown in Table 18, a sample drawing of the lightning strike panels is shown in Figure 26**.** The lightning strike panels contain material for all of the planned layers of material. The lightning strike base panels are 24” by 24” like the impact and aesthetics and smoothing panels. The impact absorbing, impact spreading, and lightning strike layers are 22” x 22” which allows the panels to fit in the opening between the two reverberation chambers used to measure transmissivity. The aesthetic film layer is recessed another ¾” to allow grounding of the lightning strike layer to the aluminum frame used to mount the panels in the window. Copper tape was also used on the base panels to help with grounding.

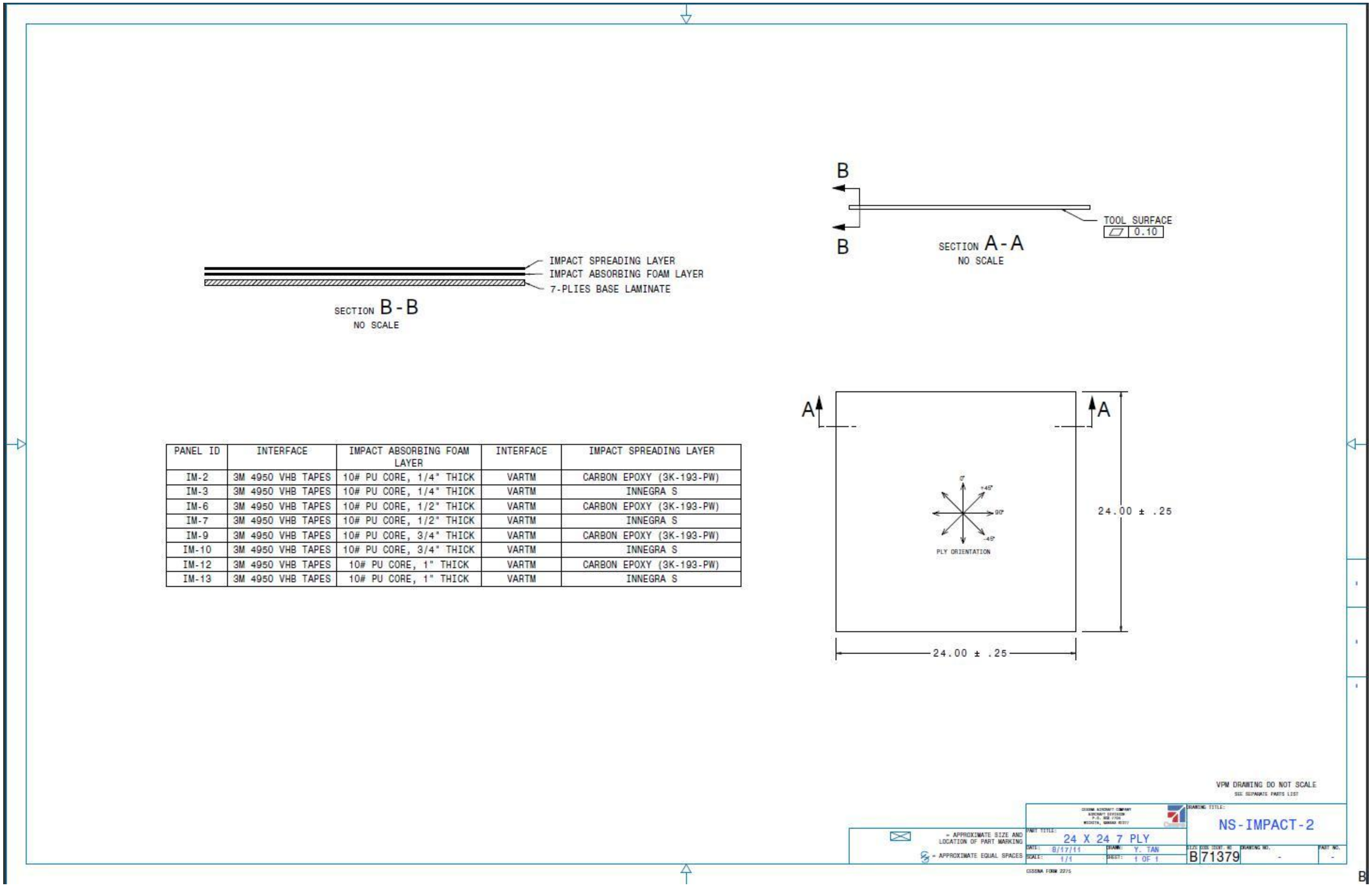
Table 19 shows the aesthetics and smoothing panels material build-up, and Figure 27 presents a sample drawing of the aesthetics and smoothing panels. Similar to the impact panels, all of the layers are 24” by 24.”

Table 17 - Impact Panel Material Build-up (1 of 2)

Panel ID	Base Panel	Interface	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer
IM-1	7 ply carbon uni epoxy	None	None	None	None
IM-2	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Carbon epoxy
IM-3	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra
IM-4	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	adhesive	0.012" aluminum sheet
IM-5	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Tegris LM
IM-6	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/2" thick	VARTM	Carbon epoxy
IM-7	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/2" thick	VARTM	Innegra
IM-8	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/2" thick	VARTM	Tegris LM
IM-9	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 3/4" thick	VARTM	Carbon epoxy
IM-10	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 3/4" thick	VARTM	Innegra
IM-11	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 3/4" thick	VARTM	Tegris LM
IM-12	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1" thick	VARTM	Carbon epoxy
IM-13	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1" thick	VARTM	Innegra
IM-14	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1" thick	adhesive	0.012" aluminum sheet
IM-15	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1" thick	VARTM	Tegris LM
IM-16	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	VARTM	Carbon epoxy
IM-17	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	VARTM	Innegra
IM-18	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	adhesive	0.012" aluminum sheet
IM-19	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	VARTM	Tegris LM
IM-20	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/2" thick	VARTM	Carbon epoxy
IM-21	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/2" thick	VARTM	Innegra
IM-22	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/2" thick	VARTM	Tegris LM
IM-23	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 3/4" thick	VARTM	Carbon epoxy
IM-24	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 3/4" thick	VARTM	Innegra
IM-25	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 3/4" thick	VARTM	Tegris LM
IM-26	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1" thick	VARTM	Carbon epoxy
IM-27	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1" thick	VARTM	Innegra
IM-28	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1" thick	adhesive	0.012" aluminum sheet
IM-29	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1" thick	VARTM	Tegris LM
IM-30	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	VARTM	Carbon epoxy
IM-31	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	VARTM	Innegra
IM-32	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	adhesive	0.012" aluminum sheet
IM-33	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	VARTM	Tegris LM
IM-34	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/2" thick	VARTM	Carbon epoxy
IM-35	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/2" thick	VARTM	Innegra
IM-36	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/2" thick	VARTM	Tegris LM
IM-37	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 3/4" thick	VARTM	Carbon epoxy
IM-38	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 3/4" thick	VARTM	Innegra
IM-39	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 3/4" thick	VARTM	Tegris LM
IM-40	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1" thick	VARTM	Carbon epoxy
IM-41	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1" thick	VARTM	Innegra
IM-42	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1" thick	adhesive	0.012" aluminum sheet
IM-43	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1" thick	VARTM	Tegris LM
IM-44	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Carbon epoxy
IM-45	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra
IM-46	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	0.012" aluminum sheet
IM-47	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Tegris LM
IM-48	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/2" thick	adhesive	Carbon epoxy
IM-49	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/2" thick	adhesive	Innegra
IM-50	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/2" thick	adhesive	Tegris LM

Table 17 – Impact Panel Material Build-up (2 of 2)

Panel ID	Base Panel	Interface	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer
IM-51	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 3/4" thick	adhesive	Carbon epoxy
IM-52	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 3/4" thick	adhesive	Innegra
IM-53	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 3/4" thick	adhesive	Tegris LM
IM-54	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1" thick	adhesive	Carbon epoxy
IM-55	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1" thick	adhesive	Innegra
IM-56	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1" thick	adhesive	0.012" aluminum sheet
IM-57	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1" thick	adhesive	Tegris LM
IM-58	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	Carbon epoxy
IM-59	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra
IM-60	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	0.012" aluminum sheet
IM-61	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	Tegris LM
IM-62	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/2" thick	adhesive	Carbon epoxy
IM-63	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/2" thick	adhesive	Innegra
IM-64	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/2" thick	adhesive	Tegris LM
IM-65	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 3/4" thick	adhesive	Carbon epoxy
IM-66	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 3/4" thick	adhesive	Innegra
IM-67	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 3/4" thick	adhesive	Tegris LM
IM-68	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1" thick	adhesive	Carbon epoxy
IM-69	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1" thick	adhesive	Innegra
IM-70	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1" thick	adhesive	0.012" aluminum sheet
IM-71	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1" thick	adhesive	Tegris LM
IM-72	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	Carbon epoxy
IM-73	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra
IM-74	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	0.012" aluminum sheet
IM-75	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	Tegris LM
IM-76	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/2" thick	adhesive	Carbon epoxy
IM-77	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/2" thick	adhesive	Innegra
IM-78	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/2" thick	adhesive	Tegris LM
IM-79	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 3/4" thick	adhesive	Carbon epoxy
IM-80	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 3/4" thick	adhesive	Innegra
IM-81	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 3/4" thick	adhesive	Tegris LM
IM-82	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1" thick	adhesive	Carbon epoxy
IM-83	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1" thick	adhesive	Innegra
IM-84	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1" thick	adhesive	0.012" aluminum sheet
IM-85	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1" thick	adhesive	Tegris LM
IM-86	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 2mm thick	VARTM	Carbon epoxy
IM-87	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 2mm thick	VARTM	Innegra
IM-88	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 2mm thick	VARTM	Tegris LM
IM-89	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 3mm thick	VARTM	Carbon epoxy
IM-90	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 3mm thick	VARTM	Innegra
IM-91	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 3mm thick	VARTM	0.012" aluminum sheet
IM-92	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 3mm thick	VARTM	Tegris LM
IM-93	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Carbon epoxy
IM-94	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra
IM-95	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Tegris LM
IM-96	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	Carbon epoxy
IM-97	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	Innegra
IM-98	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	0.012" aluminum sheet
IM-99	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	Tegris LM
IM-100	7 ply carbon uni epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (3/4" thick)	None	None

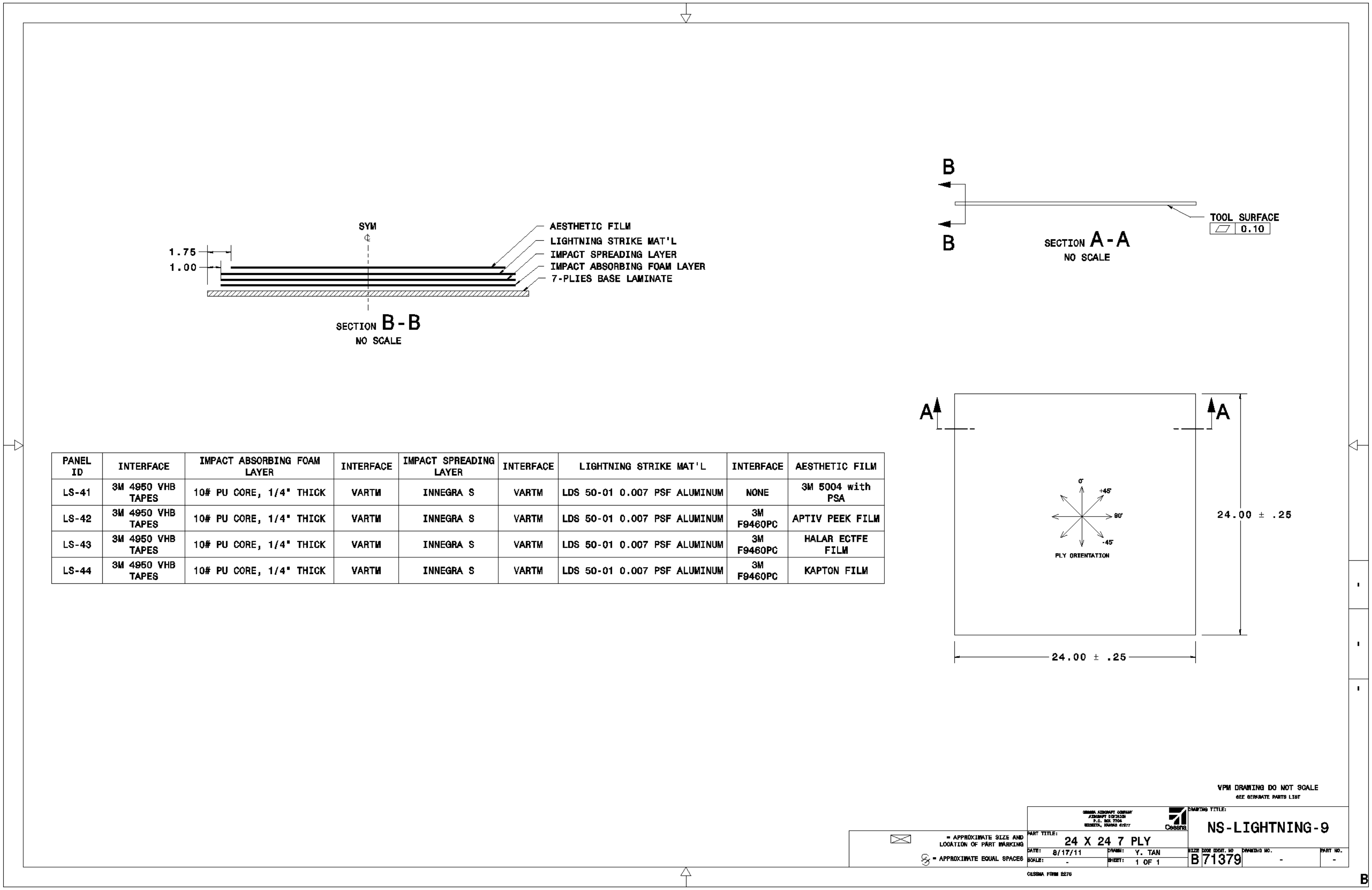


PANEL ID	INTERFACE	IMPACT ABSORBING FOAM LAYER	INTERFACE	IMPACT SPREADING LAYER
IM-2	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	CARBON EPOXY (3K-193-PW)
IM-3	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S
IM-6	3M 4950 VHB TAPES	10# PU CORE, 1/2" THICK	VARTM	CARBON EPOXY (3K-193-PW)
IM-7	3M 4950 VHB TAPES	10# PU CORE, 1/2" THICK	VARTM	INNEGRA S
IM-9	3M 4950 VHB TAPES	10# PU CORE, 3/4" THICK	VARTM	CARBON EPOXY (3K-193-PW)
IM-10	3M 4950 VHB TAPES	10# PU CORE, 3/4" THICK	VARTM	INNEGRA S
IM-12	3M 4950 VHB TAPES	10# PU CORE, 1" THICK	VARTM	CARBON EPOXY (3K-193-PW)
IM-13	3M 4950 VHB TAPES	10# PU CORE, 1" THICK	VARTM	INNEGRA S

Figure 25: Sample drawing for the impact panels.

Table 18 - Lightning Strike Panel Material Build-up

Panel ID	Base Panel	Interface	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film
LS-1	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	0.016 psf expanded aluminum foil	none	Integument film
LS-2	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	0.029 expanded copper foil	none	Integument film
LS-4	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-5	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-6	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	None	LORD Spray Material	none	Integument film
LS-7	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none
LS-8	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Tegris LM	None	Integument with integrated LSP & PSA	none	none
LS-9	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 3/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-10	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 3/4" thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-11	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-12	7 ply carbon uni epoxy	VHB Tape	20 pcf PU core, 1/4" thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-13	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-14	7 ply carbon uni epoxy	VHB Tape	30 pcf PU core, 1/4" thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-15	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	VARTM	0.016 psf expanded aluminum foil	none	Integument film
LS-16	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	VARTM	0.029 expanded copper foil	none	Integument film
LS-18	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-19	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-20	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	None	LORD Spray Material	none	Integument film
LS-21	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none
LS-22	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 1/4" thick	adhesive	Tegris LM	None	Integument with integrated LSP & PSA	none	none
LS-23	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 3/4" thick	adhesive	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-24	7 ply carbon uni epoxy	VHB Tape	3 pcf metallic honeycomb, 3/4" thick	adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-25	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-26	7 ply carbon uni epoxy	VHB Tape	6 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-27	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-28	7 ply carbon uni epoxy	VHB Tape	9 pcf metallic honeycomb, 1/4" thick	adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-29	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra S	VARTM	0.016 psf expanded aluminum foil	none	Integument film
LS-30	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra S	VARTM	0.029 expanded copper foil	none	Integument film
LS-32	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-33	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-34	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Innegra S	None	LORD Spray Material	none	Integument film
LS-35	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none
LS-36	7 ply carbon uni epoxy	VHB Tape	Soric XF, 2mm thick	VARTM	Tegris LM	None	Integument with integrated LSP & PSA	none	none
LS-37	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-38	7 ply carbon uni epoxy	VHB Tape	Soric XF, 6mm thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-39	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 2 mm thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	Integument film
LS-40	7 ply carbon uni epoxy	VHB Tape	Soric LRC, 2 mm thick	VARTM	Innegra S	None	Integument with integrated LSP & PSA	none	none
LS-41	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	none	3M 5004
LS-42	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	adhesive	Aptiv PEEK Film
LS-43	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	adhesive	Halar ECTFE Film
LS-44	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	LDS 50-01 0.007 psf aluminum	adhesive	Kapton film
LS-45	7 ply carbon uni epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (3/4" thick)	None	None	None	None	none	none
LS-46	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	Nanocomp sheet (9-11 gsm, 1 + 1/2 layers)	none	Integument film
LS-47	7 ply carbon uni epoxy	VHB Tape	10 pcf PU core, 1/4" thick	VARTM	Innegra S	VARTM	Nanocomp sheet (15 gsm, 1 layer)	none	Integument film

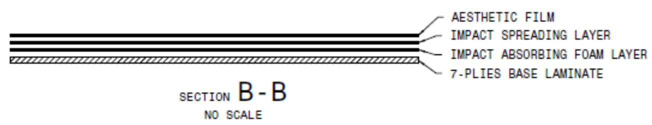


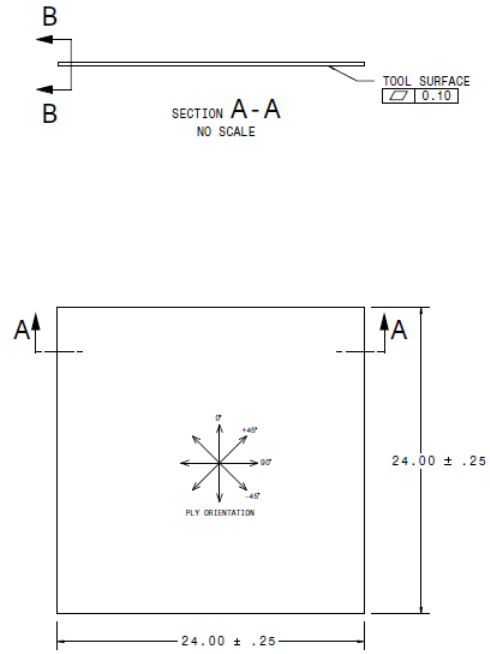
PANEL ID	INTERFACE	IMPACT ABSORBING FOAM LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	LIGHTNING STRIKE MAT'L	INTERFACE	AESTHETIC FILM
LS-41	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	VARTM	LDS 50-01 0.007 PSF ALUMINUM	NONE	3M 5004 with PSA
LS-42	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	VARTM	LDS 50-01 0.007 PSF ALUMINUM	3M F9460PC	APTIV PEEK FILM
LS-43	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	VARTM	LDS 50-01 0.007 PSF ALUMINUM	3M F9460PC	HALAR ECTFE FILM
LS-44	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	VARTM	LDS 50-01 0.007 PSF ALUMINUM	3M F9460PC	KAPTON FILM

Figure 26: Sample drawing for the lightning strike panels.

Table 19 - Aesthetics and Smoothing Material Build-up

Panel ID	Base Panel	Interface	Imact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film
AS-1	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	None	Integument Film with PSA
AS-2	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	None	Integument Film with PSA
AS-3	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	None	Integument Film with PSA
AS-4	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	None	Integument Film with PSA
AS-5	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	None	Integument Film with PSA
AS-6	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	None	Integument Film with expanded aluminum foil & PSA
AS-7	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	None	& PSA
AS-8	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	None	& PSA
AS-9	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	None	Integument Film with expanded aluminum foil & PSA
AS-10	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	None	& PSA
AS-11	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	None	3M 5004 Film with PSA
AS-12	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	None	3M 5004 Film with PSA
AS-13	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	None	3M 5004 Film with PSA
AS-14	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	None	3M 5004 Film with PSA
AS-15	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	None	3M 5004 Film with PSA
AS-16	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	adhesive	Aptiv PEEK Film
AS-17	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Aptiv PEEK Film
AS-18	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Aptiv PEEK Film
AS-19	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	adhesive	Aptiv PEEK Film
AS-20	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	adhesive	Aptiv PEEK Film
AS-21	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	adhesive	Halar ECTFE Film
AS-22	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Halar ECTFE Film
AS-23	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Halar ECTFE Film
AS-24	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	adhesive	Halar ECTFE Film
AS-25	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	adhesive	Halar ECTFE Film
AS-26	7 ply carbon unitape epoxy	VHB Tape	1/4" PU 10 pcf core	VARTM	Innegra	None	None	adhesive	Kapton film
AS-27	7 ply carbon unitape epoxy	VHB Tape	Non-metallic honeycomb core (1/4" thick, 4 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Kapton film
AS-28	7 ply carbon unitape epoxy	VHB Tape	Metallic honeycomb core (1/4" thick, 5052, 6 pcf)	adhesive	0.012" aluminum sheet	None	None	adhesive	Kapton film
AS-29	7 ply carbon unitape epoxy	VHB Tape	Polydamp Hydrophobic Melamine with PEEK skin (1/2" thick)	None	None	None	None	adhesive	Kapton film
AS-30	7 ply carbon unitape epoxy	VHB Tape	Soric XF, 2mm	VARTM	Innegra	None	None	adhesive	Kapton film





PANEL ID	INTERFACE	IMPACT ABSORBING FOAM LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	AESTHETIC FILM
AS-1	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	NONE	INTEGUMENT FILM WITH PSA
AS-6	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	NONE	INTEGUMENT FILM WITH EXPANDED AL. FOIL & PSA
AS-11	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	NONE	3M 5004 FILM WITH PSA
AS-16	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	3M F9460PC	APTIV PEEK FILM
AS-21	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	3M F9460PC	HALAR ECTFE FILM
AS-26	3M 4950 VHB TAPES	10# PU CORE, 1/4" THICK	VARTM	INNEGRA S	3M F9460PC	KAPTON FILM

VPM DRAWING DO NOT SCALE

NS-AES-1

24 X 24 7 PLY

8/17/11 Y. TAN 1/1 1 OF 1

B 71379

Figure 27: Sample drawing for aesthetics and smoothing panels.

7.1.3 Manufacturability

The manufacture of the panels was contracted to a supplier. A project was undertaken to capture all meaningful input on manufacturability of all the materials being used in the STAR-C^2 protective skin panels. This data allowed an assessment of the suitability of materials for applications to protective skins. Minimizing the time and bother to the supplier was a critical part of the project.

Brainstorming the manufacturing properties required led to the topics included in Figure 28. The goal of the data collection process was to be very thorough without taking up a lot of the manufacturer's time. The methodology used to collect the information was to go through the topics in Figure 28 for each of the materials shown in Tables 12 – 16 during a meeting with the two people at the supplier who had participated in manufacturing all of the panels. The data was collected during a meeting at the supplier's facility.

The assumption was that each of the properties for each of the materials did not have any special manufacturing characteristics. The goal was to discuss the exceptions rather than every property of every material in detail. The data collection plan was successful. A great deal of information was collected.

The notes collected for working with each of the materials are presented in Tables 20-43. The results are summarized visually in Table 44**Error! Reference source not found.**.

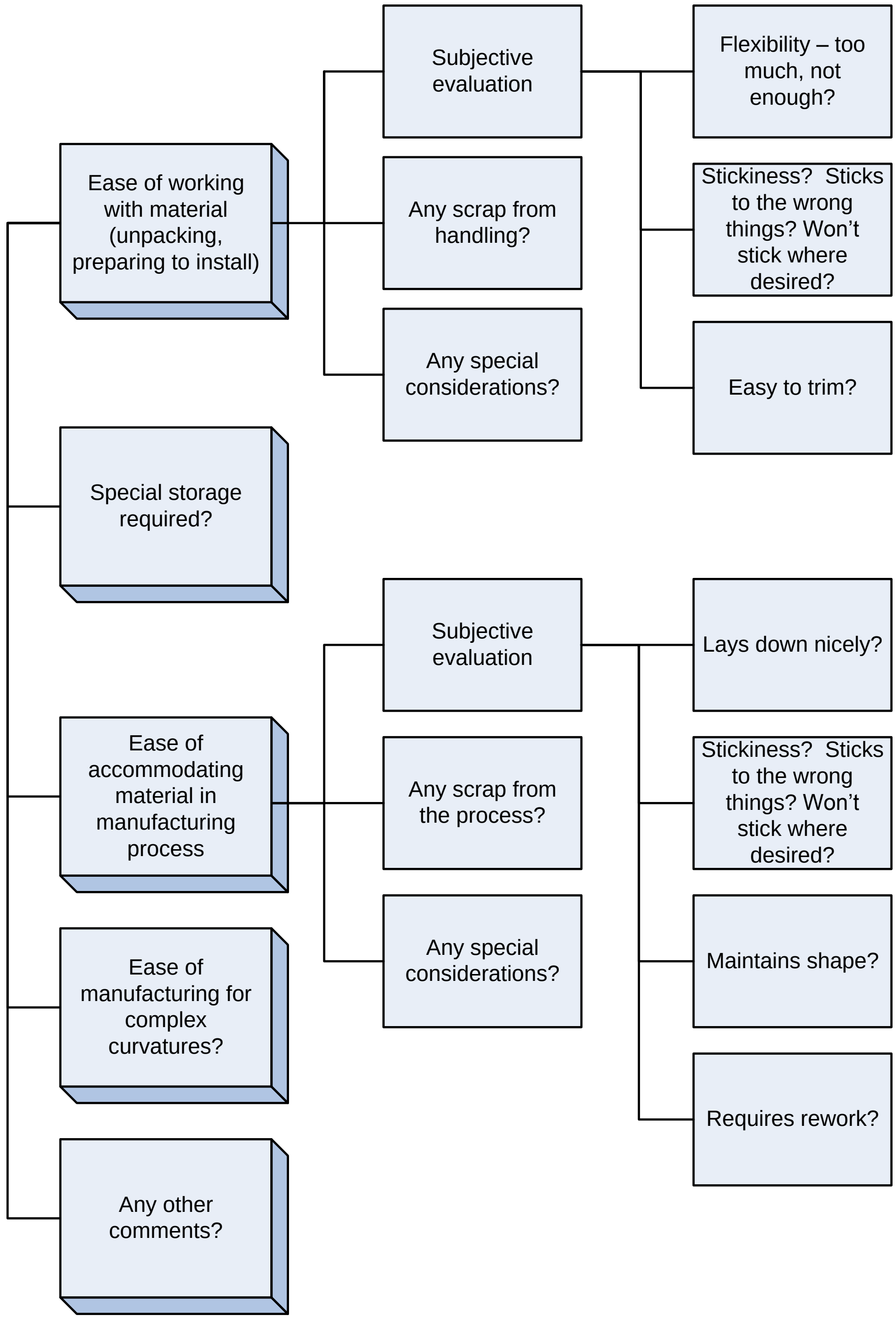


Figure 28: Material manufacturing data sought for each material used.

Table 20 - Notes for Core Materials

Core (10 pcf, 20 pcf, and 30 pcf)	No curvature possible
	10 pcf was easy to cut, even the thicker pieces
	20 pcf and 30 pcf required the band saw; the ¾” and 1” bogged down the band saw
	Had to move the 20 pcf and 30 pcf from the core cutting area because of dust; even cutting with a razor left a fine grit which required extra cleaning. Core needs its own room.
	The 10 pcf core was so porous that it had to be kept covered so it would not get dirty
	Humidity would probably be a factor – climate control storage would be required
	Over 10 pcf the core is machinable
	Didn’t like the oven – used cold bond

Table 21 - Notes for Non-Metallic Core

4 pcf non-metallic core	Could put in a compound, complex shape with core stabilization
	Could preform
	Couldn’t drill or punch – need to prepot where you want to cut or put a hole
	Didn’t like the oven – used cold bond

Table 22 - Notes for Metallic Core

Metallic Core (3 pcf, 6 pcf, and 7.9 pcf	3 pcf had same problem with drilling as 4 pcf non-metallic – too light. Instead punched from reverse and then used holes from punch to guide drill bit
	6 pcf and 7.9 pcf could be drilled and punched.
	All thicknesses of 6 pcf were easy to work with.
	Smaller thicknesses of 7.9 pcf were easy to work with. The ¾” and 1” 7.9 pcf were a little bit difficult to work with.
	Metallic cores were pretty rigid – not pliable to shape something out of them
	Didn’t like the oven – used cold bond

Table 23 - Notes for Soric

Soric	Easy to cut/trim, easy to use, clean, didn’t leave fibers, wasn’t itchy.
	Used a lot of resin
	No difference in working with different cell sizes
	Could be shaped with splicing
	No stretch or give – tears at a certain point
	No downsides
	The big cells were fibery – soaked up a lot of resin and didn’t like to stick to the VHB double-sided tape

Table 24 - Notes for Polydamp Hydrophobic Melamine with PEEK Skin

Polydamp Hydrophobic Melamine with PEEK Skin	Tore itself up – removing adhesive from backing would tear a bunch of foam out – extremely fragile
	Not hard to stick on
	Can't bend – if bent towards backing it tears the surface aluminum skin; if bent towards the aluminum skin, it bends the aluminum skin

Table 25 - Notes for Innegra S

Innegra S	Everybody liked it. Mistook it for 7781 dry glass
	Took resin well
	Stuck down well
	Had to cut it different than other materials – it would fray
	Cut with scissors oversized and then trim once coated with resin
	Extremely flexible
	Could change the fiber direction with the resin brush once wet

Table 26 - Notes for Tegris

Tegris LM	Didn't want to stick; wouldn't absorb resin – resin would bead
	Using a punch would cause delamination
	Using a drill would fray the material
	Once the resin was broken the fiber would fray
	It was a pain to cut – the 2 x 2 basket weave would come apart
	Not much better in resin
	Couldn't imagine making a real part out of it that would go through inspection successfully
	Didn't try molding – web site suggests it could be molded

Table 27 - Notes for Carbon Epoxy

Carbon Epoxy	Common place use
	Flexible/bendable
	Soaks up resin well
	Easy to sand
	Extremely sharp when dry
	Extremely strong
	One of the thicker and heavier materials
	Lots of experience with it

Table 28 - Notes for Aluminum

Aluminum (0.012" thick)	Very thin
	Attaching the honeycomb to the aluminum dimpled the aluminum skin
	Very hard to control surface quality
	Used metal bond process in oven – temperature and differences in expansion caused major curvature of the panels

Table 29 - Notes for Integument Film with PSA

Integument film with PSA	Pretty easy to lay down
	Stuck when down – had to be careful
	Won't bend or stretch – couldn't work around a tight curve or radius or shape – would need to splice
	Would work well for a sidewall with a large radius

Table 30 - Notes for 3M 5004 with PSA Aesthetic Film

3M 5004 with PSA	Hard to find the PSA
	Stuck easily
	Easier to work with than Integument
	It would stretch
	Could probably force around a shape better
	The finish of the film is sensitive to touching; the surface quality can be changed by touching

Table 31 - Notes for Halar

Halar	Doesn't like heat – low heat dimpled it
	Put it in the oven at 190° for seconds to try to get it to stick – turned it brittle
	Extremely rigid – no pliability – would crease
	Would probably tear
	Didn't want to stick to anything – that could have been the transfer tape, but neither side wanted to stick
	Scrapped quite a bit of the material trying to get it to stick and look nice
	Spray adhesive might have worked better or a different transfer tape – it didn't get a fair shake

Table 32 - Notes for Aptiv PEEK with PSA

Aptiv with PSA	Laid down easily
	Thinner than Integument
	Could hold one end up and slowly work down
	Wouldn't stretch
	Adhesive-wise – had good PSA. Had time to work.
	Once it stuck, it was down – would tear trying to get it up

Table 33 - Notes for Kapton

Kapton	Rigid like Halar – creases if you bend it
	Could wrinkle like aluminum skin if you laid it down wrong
	Spray adhesive might have worked better or a different transfer tape – it didn't get a fair shake

Table 34 - Notes for Integument with LSP and PSA

Integument with LSP & PSA	Really easy to lay down.
	Mesh made it durable – could pull and stretch. Easy to attach.
	PSA held the screen in place
	Thick enough that it would stabilize what it went over
	Could put on large radii. It wouldn't bend too far.

Table 35 - Notes for 0.016 psf Expanded Aluminum

0.016 psf expanded aluminum	Very easy to work with
	Borderline being fragile – no scrap
	Very easy to cut
	Stuck well. At first would act like it didn't want to stick, then laid down and stuck.

Table 36 - Notes for 0.029 psf Copper

0.029 psf copper	Very fragile – easy to tear
	Had to sandbag to cut – just cutting with a razor snagged and ripped
	Would wrinkle on itself
	Brushing resin on it would snag and bend the mesh
	Copper on top of Innegra made an aesthetically pleasing panel
	Bendable, pliable
	Took resin; stuck good

Table 37 - Notes for LDS 50-01 0.007 psf Aluminum

LDS 50-01 0.007 psf aluminum	Extremely fragile
	Came with flaws/defects; there wasn't one perfect sheet in the pile
	More challenging than copper
	Very easy to tear
	Had to pick up by two corners because it would not support itself
	Stuck well once coated with resin and placed on the part
	Laying up in prepreg might work out ok. Not good for wet layup.

Table 38 - Notes for Proprietary Spray Material

Proprietary Spray Material	Laid up on panels; used air nozzle to separate spray material from sheet where it was sprayed
	There was dry overspray – had to sand. Reminded them of a copper spray they use. It works best for them.

Table 39 - Notes for Carbon Nanotube Material

Nanocomp CNT	Extremely delicate – especially running with the fibers – basically an unsupported unidirectional material
	Cut easily but if it folded over it clogged the scissors
	Wetted out nicely but extra care had to be taken not to move the fibers around

Table 40 - Notes for VHB Double-sided Tape

VHB Double-Sided Tape	24” wide a challenge
	If it touched to itself, it stuck
	Cut well, laid down well, easy to use once they got used to it
	Stretches to a point; could potentially cut the backing and get it to bend
	Great adhesive

Table 41 - Notes for Aeropoxy

Aeropoxy	Easy to work with
	Long pot life
	Real slow cure at room temperature
	No provisions for accelerated cure (according to the web site)
	12-13 hour cure (overnight) – would still be gummy in the morning – couldn’t sand
	Never gets hard/brittle; it will get harder
	Gives enough to keep from damaging itself
	Very consistent – not too thick or too thin/runny
	Could have sped the process up by using the other catalyst – there were 2 listed

Table 42 - Notes for AF 163 0616 Adhesive

AF 163 0616	BMS – Kaman standard
	Did good on foam cores (whole sections)
	For butt joints on foam, it would wick up a little
	To splice with foam cores, would need to add adhesive to get a good bond
	Easy to bond
	Easy to see where it’s bonded (color)

Table 43 - Notes for 3M 4950PC Transfer Tape

Transfer Tape	Extremely hard to work with
	Smaller width is easier to work with
	2’ wide chunk – could cut strips and get them to lay down
	The things it would stick to were really stuck
	It showed on the transparent films – would ball up
	Where it was put under something so that it didn’t show, it looked fine
	Didn’t like sticking to plastics
	Grabbed Innegra and aluminum
	Wouldn’t stick to anything with a glassy, smooth finish
	Doesn’t maintain shape; backing held it together
	Don’t think you could work it around anything

Table 44 - Visual Representation of the Material Manufacturing Data

Material	Special Material Storage Required	Durability during manufacturing	Absorbs resin well	Flexible	Easy to Drill/Punch	Maintains shape	Easy to cut/trim	Easy to install	Wants to stick
Impact Absorbing									
Polyurethane foam core									
Non-metallic core									
Metallic core									
Soric									
Polydamp Hydrophobic Melamine with PEEK Skin			N/A						
Impact Spreading									
Innegra									
Tegris									
Carbon Epoxy									
Aluminum			N/A						
Lightning Strike Protection									
Integument with LSA & PSA			N/A		N/A				
0.016 psf expanded aluminum					N/A				
0.029 psf copper					N/A				
LDS 50-01 0.007 psf aluminum					N/A				
Nanocomp CNT					N/A				
LORD Spray			N/A		N/A				
Films									
Integument with PSA			N/A		N/A				
3m 5004 with PSA			N/A		N/A				
Halar			N/A		N/A				
Aptive PEEK with PSA			N/A		N/A				
Kapton			N/A		N/A				

Some general observations can be made from this data: 1) working with materials the manufacturer already had a great deal of experience was easier (e.g., carbon epoxy); 2) films with pressure sensitive adhesive on them were much easier to work with than films without where transfer tape had to be used to stick the film down; 3) Innegra was a good material with which to work; 5) the flexible lightning strike protection materials were especially difficult; and 6) the vast majority of these materials would not easily conform to a complex curvature shape.

7.1.4 Base Panel Inspection

The base substrate panels were built to represent the primary structure and to serve as the surface to which the protective skins are attached. The base panels were manufactured by Cessna. The base panels consist of seven plies of carbon unitape with epoxy (Material F990201) which is NCT321-G150/NAS-S-12K-UNI from Newport. The panel size is 24” x 24” with gross thickness of 0.043”. The panels were fabricated oversize to 24” ± .25” and trimmed to size. The panel geometry and the stacking sequences of the layers are show in Figure 29.

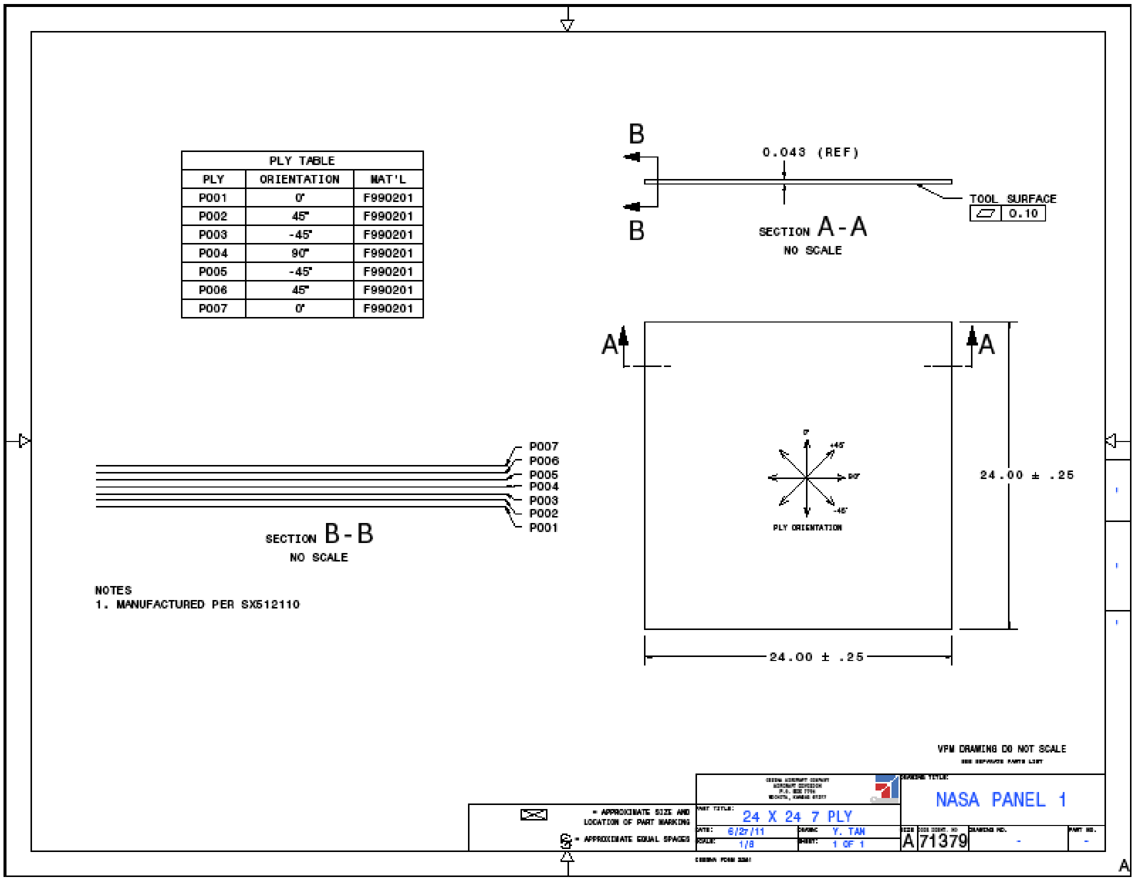


Figure 29: Substrate panel definition.

The length and width of each panel were measured at the five locations per side and recorded to the nearest 0.05" as shown in Figure 30. Each base panel was weighed to the nearest 0.01 lb, and the weight was recorded. The dimensions and weights are presented in Appendix B – First-Generation Base Panel Inspection Results. There was a noticeable correlation between panel weight and at least one side of the dimensions. Panel weights varied between 1.28 lbs and 1.36 lbs. Panel areal weight was calculated based on panel weight and average panel length and width. Areal weights varied between 0.323 lbs/ft^2 and 0.338 lbs/ft^2.

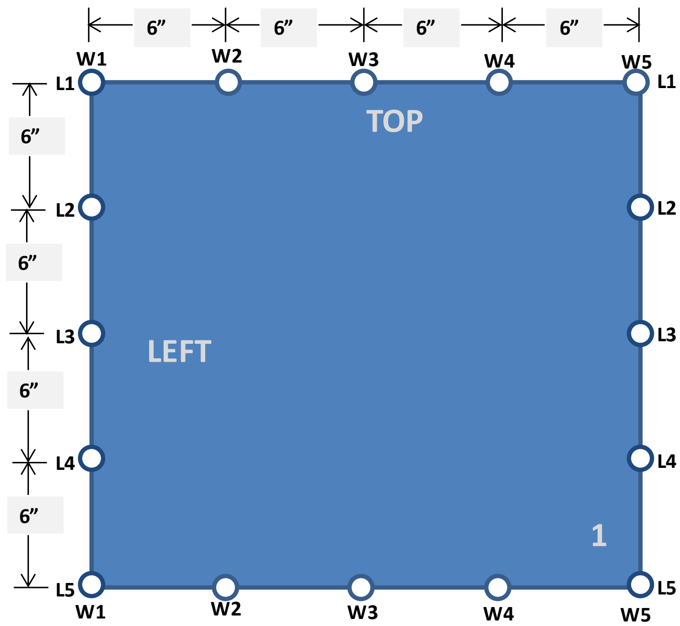


Figure 30: Base substrate panel length and width measuring locations.

The base panels were received and inspected using ultrasonic or thermographic methods. Average ultrasonic attenuation was measured and used to assign each panel to one of the categories of test articles (impact, lightning strike, or aesthetics and smoothing). The following subsections will describe the ultrasonic/thermographic inspection, problems encountered with high levels of porosity in the panels, and panel assignment to a test article category.

7.1.5 Inspection for Voids and Porosity

All of the base substrate panels were inspected by either ultrasonic inspection or thermography or both. When the initial large batch of panels required inspection, Cessna’s thermography camera was unavailable due to upgrading. Thru-transmission ultrasonic (TTU) inspection in a gantry was conducted for the first large batch of panels (see Figure 31 for a view of eight of the panels in the gantry undergoing ultrasonic inspection). When the thermography camera returned to operation, some thermographic images were made to compare to the ultrasonic images, and the final panels were inspected using thermography. The concern was being able to determine what new damage was inflicted due to testing.

Figure 31: Eight base substrate panels in gantry undergoing ultrasonic inspection.

Appendix C – First-Generation Thermography Report shows the results of all inspections of the base panels by either ultrasonic testing or thermography. The results are in order of base panel number. The appendix also shows the post-testing inspection results for the Impact and Lightning Strike panels. The index at the beginning of the document is for the page numbers for the base substrate panel inspection. Where two numbers are shown for one panel, both ultrasonic and thermographic inspections were done of that base panel.

Figure 32 shows the TTU inspection of base substrate panel 1. The thermographic inspection is shown in Figure 33. Although the boxes on the two figures appear to be calling out different features, similarities can be observed between the two images.

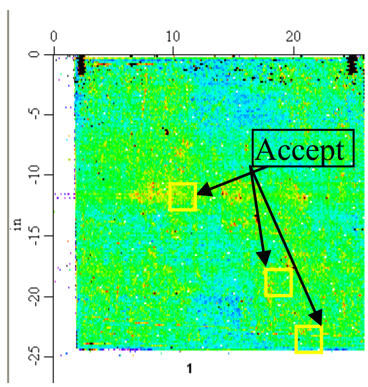


Figure 32: Ultrasonic inspection of base substrate panel 1.

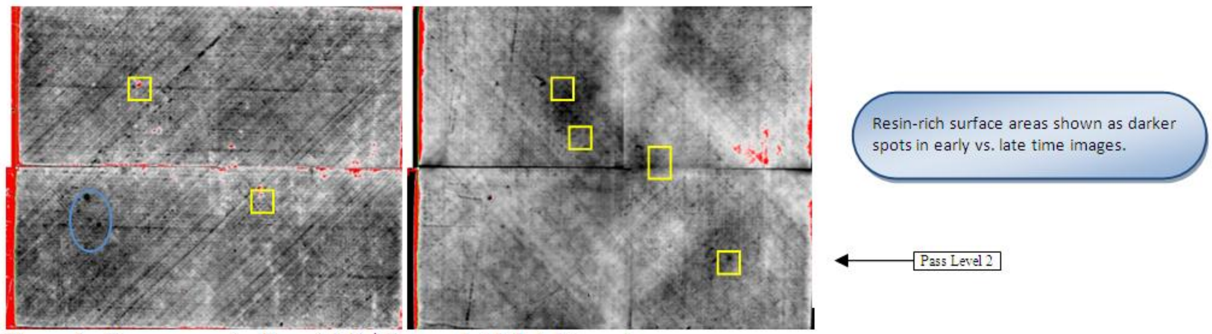


Figure 33: Thermographic inspection of base substrate panel 1 (1st Derv. -0.42 & 0.94 sec).

Figure 34 shows the ultrasonic inspection of base substrate panel 64. For comparison, Figure 35 shows the thermographic inspection of the same panel before any modification or testing. With experience, a trained eye can see that the two different inspection techniques show similar features in the panel. The trained eyes that did the initial inspections of the base panels also conducted the final inspections and interpretation of results.

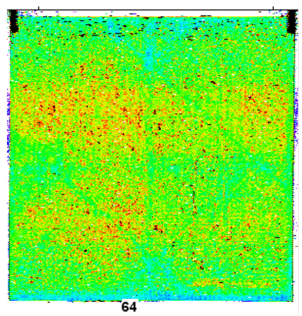


Figure 34: Ultrasonic inspection of base panel 64.

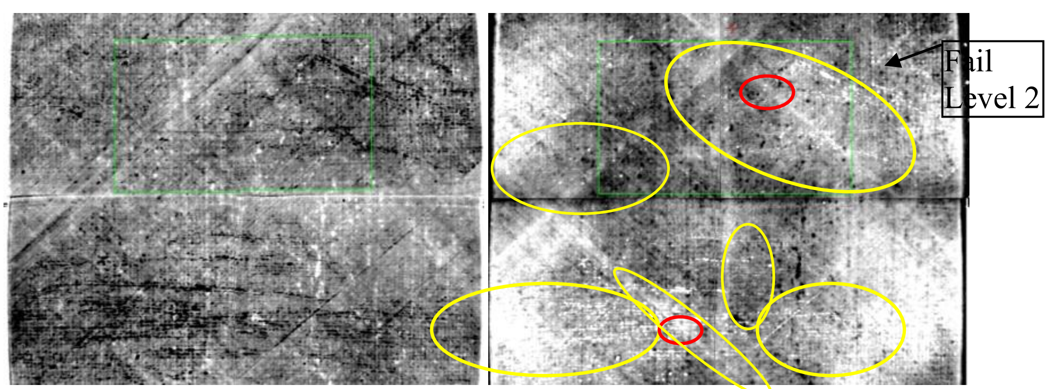


Figure 35: Thermographic inspection of base panel 64 (1st Derv. -0.3 & Peak Ampl.-Pos 2nd Derv).

7.1.6 Porosity

As could be seen in Figure 33 and Figure 35, notation indicates that these panels "Fail Level 2." The levels are in accordance with CSTI009 (Cessna proprietary specification: NDI – Inspection of Metal Adhesive Bonded, Advanced Composite, and Brazed Structures). Level 2 acceptance size limit is

0.25 in^2. Ultrasonic attenuation values recorded in the table on page 3 in Appendix C are not the worst areas on the panel, but an averaged value. High attenuation indicates porosity in the panel.

Panels 23 and 159 were identified as having very high porosity and worthy of much closer inspection. The UT figure for Panel 23 copied from Appendix C is shown in Figure 36. The thermographic images are shown in Figure 37. The yellow box in the right thermography picture in Figure 37 shows the sectioned area, and the 0° orientation is shown with the green arrow to the lower right of the right thermography picture. The UT image for Panel 159 copied from Appendix C is shown in Figure 38. The yellow boxes in the middle thermography picture show the sectioned areas, and the green arrow below the middle thermography picture shows the 0° orientation. Table 45 (taken from Appendix C) shows the optically determined porosity, local attenuation, and averaged attenuation over the sectioned areas. These panels (23 and 159) were among the worst for high porosity.

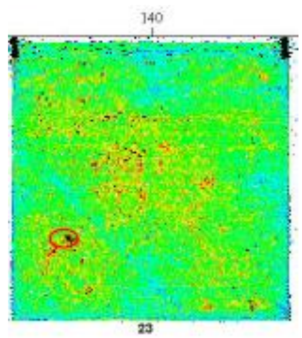


Figure 36: Ultrasonic inspection of base panel 23.

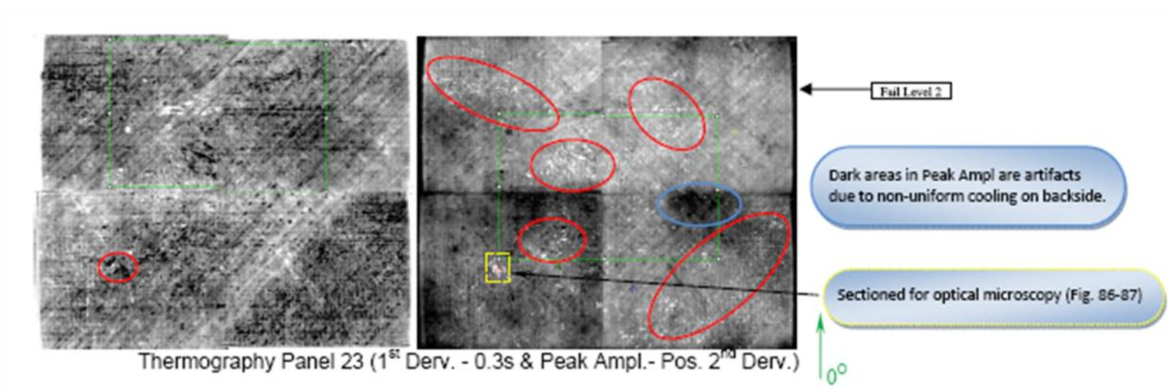


Figure 37: Thermography image of base panel 23.

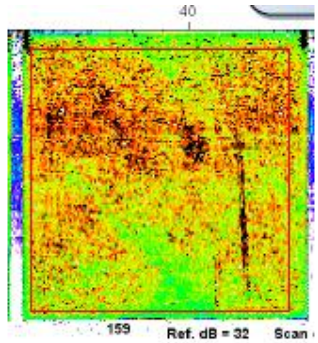


Figure 38: UT image for base panel 159.

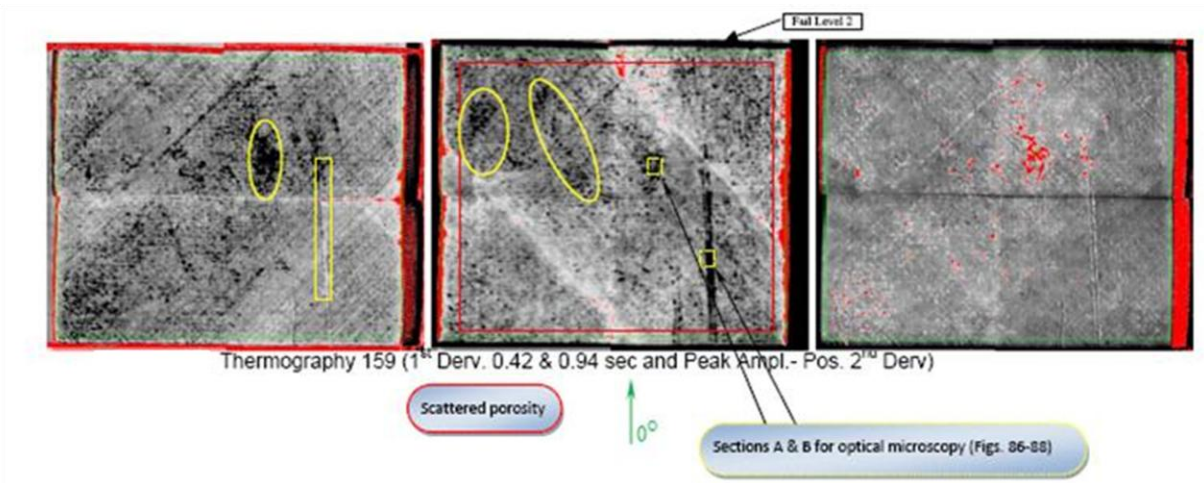


Figure 39: Thermographic image for base panel 159.

Table 45 - PE 5 MHz UT Attenuation vs. Void Content (Optical)

Panel ID pcf	Porosity averaged over ~1 sq. in. (%VC)	Local PE-UT Attenuation (dB)	Average Max Attenuation in Entire Panel (dB)
159A	3.7	-20	-9
159B	2.9	-18	-9
23	3.9	-19	-10

The photomicrography analysis of void content for the sectioned samples is shown in Figure 40, Figure 41, and Figure 43 (again copied from Appendix C). The differences between the three figures are an increasing number of polishes: from first to second to third polish. Figure 42 contains images of only the two sections from Panel 159.

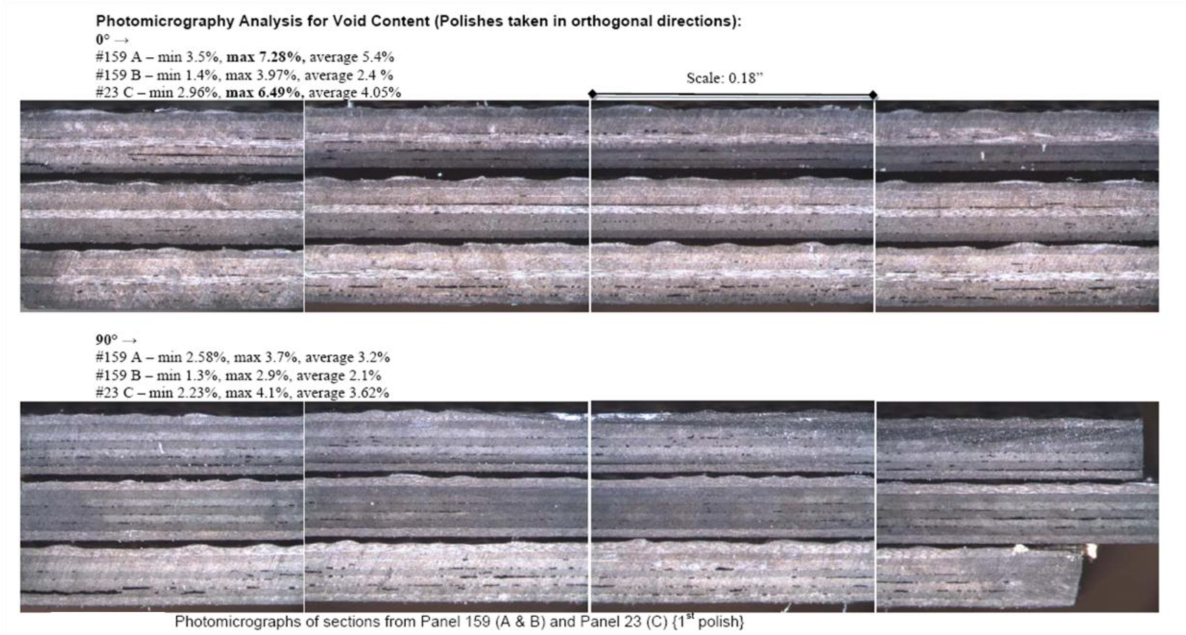


Figure 40: 0° and 90° photomicrography analysis (first polish) for void content of base panels 159 and 23.

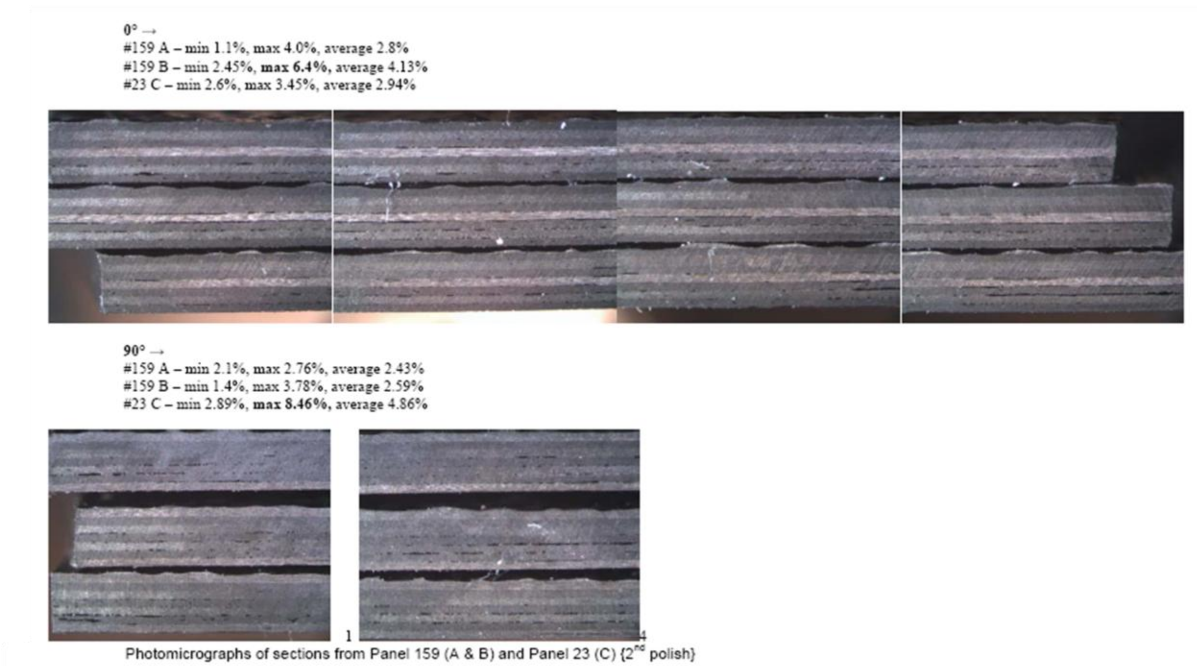


Figure 41: 0° and 90° photomicrography analysis (second polish) for void content of base panels 159 and 23.

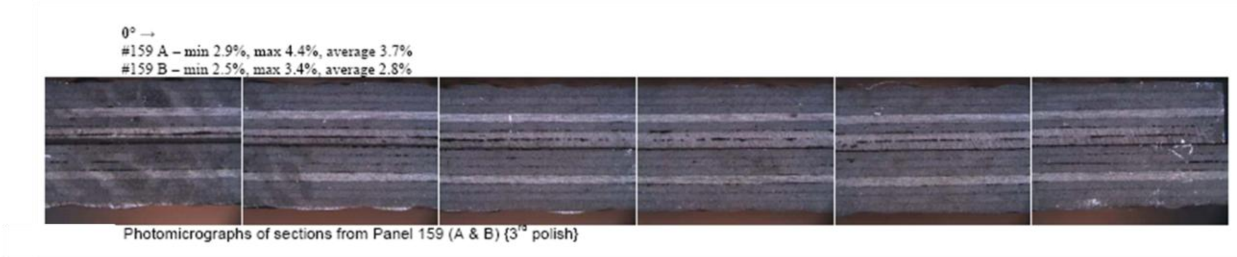


Figure 42: 0° and 90° photomicrography analysis (third polish) for void content of base panel 159.

Appendix C explains these results by saying, "Many outside studies have found a linear relation between attenuation, porosity and mechanical strength – if porosity voids are spherically shaped and uniformly distributed (e.g., in fabric). However, with UNI laminates the porosity, size, shape (often cigar shaped) and distribution dramatically affect void content correlation to UT attenuation – and porosity content to mechanical strengths as well."

Efforts to trace the variations in porosity to variations in materials or manufacturing processes during production were extensive but not conclusive. Figure 43, based on the panel inspection results, demonstrates that something happened between the manufacture of panels 1-31 and panels 32-106. Additional investigation was undertaken to determine why there was a difference. No specific root cause was identified. The best hypothesis (after an in-depth investigation consisting of two different team members visiting the manufacturing facility at two different times) was that perhaps the rolls of material were not sealed well and condensation took place when the material refroze after being out of the freezer. It is possible that the vacuum pressure and temperature were not sufficient to 'flash off' the water and that water caused porosity.

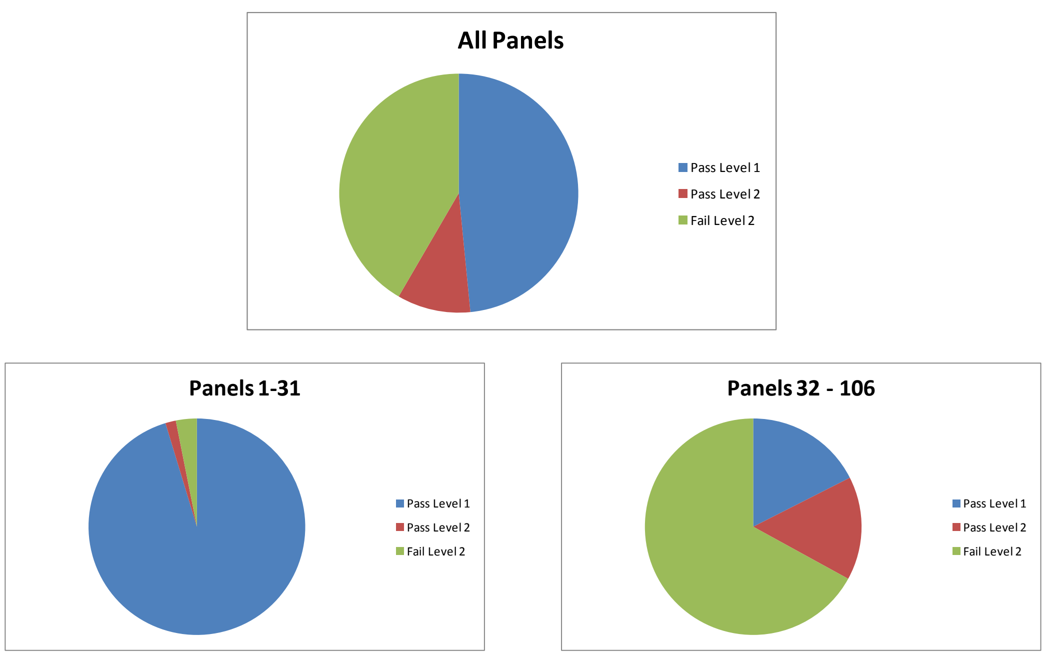


Figure 43: Base substrate panel porosity test results.

For an actual aircraft application, this porosity may not matter. Failing Level 2 is still acceptable. The porosity did have an impact on the research results by causing some data resolution loss.

7.1.7 Base Substrate Panel Assignment to Test Article Category

The initial attempt at assigning base substrate panels to test article category was to assign "Pass Level 1" articles to impact testing and lightning strike if any were left, "Pass Level 2" articles to lightning strike articles, and "Fail Level 2" articles to aesthetics and smoothing articles. There were so few "Pass Level 1" articles that all were assigned to impact. Because of the need to change direction of hole pattern for the impact panels (discovered after initial impact testing), some of the 'Fail level 2' panels had to be assigned to impact test articles. Similarly, lightning test articles wound up with a large number of "Fail level 2" panels.

There were cases for both impact and lightning strike testing where the impact took place in an area of high porosity. The thermographic inspection result was 'no apparent damage' since no damage could be detected in a region of high porosity. Unfortunately, this left doubt about whether the protective skin passed the test or not. In order to not eliminate a material that might pass the requirements, the "no apparent damage" assessment was assumed to be "no damage" or a pass.

7.2 Impact

Impact testing was conducted on one bare substrate panel and 98 protective skins placed over the bare substrate panel. There were three impactor diameters (0.5", 1.0", and 1.75") and three energy levels (50 in-lbs, 180 in-lbs, and 250 in-lbs). An impact test facility was constructed to enable rapid testing with minimal variation in impacts.

Base substrate panels were inspected with non-destructive evaluation (either ultrasonic or thermographic techniques) prior to and after impact testing. Data, consisting of both visual and non-destructive evaluation, was collected for analysis. The following subsections provide analysis of the data and draws conclusions about which materials and material combinations best meet the impact requirements.

7.2.1 Requirements

There are two primary requirements for impact damage as shown in Table 46. The critical requirement is that the material be able to withstand a 180 in-lb impact with no damage. Terminal velocity for 1" hail is 13.3 in-lbs and 2" is 213 in-lbs. The requirement for 180 in-lbs was selected to represent 90-95% probability (less than 5-10% of occurrence). This requirement applies to the hail-ground zone on the aircraft (top of the aircraft).

Another primary requirement for impact is that damage which could require repair is visible. Current composite structures are difficult because damage sufficient to require repair can occur but not be visible to the eye. AC20-107B (Ref. 2) defines five categories of damage. Category 1 is sufficiently small enough to be ignored. Category 5 is so severe that it will be visible. Categories 2, 3, and 4 are in between and should require inspection to be sure that repair is not required. The requirement for the STAR-C^2 skins relative to impact is to make all Category 2, 3, and 4 damage visible so that inspection can be performed.

Table 46 - Primary Requirements for Impact

Impact Energy*	180 in-lbs (5 lb weight dropped from height of 36 in)
Visible Damage	Category 2, 3, & 4 (AC20-170B) damage visible to show that inspection is not required
*Critical Requirement	

In order to expand the information obtained about the ability of the various materials to withstand impacts, the test matrix consists of three impact energies (50 in-lbs, 180 in-lbs, and 250 in-lbs) with three different impactor diameters (0.5", 1.0", and 1.75") as shown in Table 47. The requirement is 1.0" at 180 in-lbs. Realistically the protective skins do not need to pass the 180 in-lbs or 250 in-lbs for the 0.5" impactor or the 250 in-lbs for the 1.0" impactor. The panels should pass all energy conditions for the 1.75" impactor.

Table 47 - Impact Test Conditions

Impactor Diameter (in)	0.5	1.0	1.75
Impactor Weight (lbs)	5.0	5.0	5.0
50 in-lbs drop height (in)	10	10	10
180 in-lbs drop height (in)	36	36	36
250 in-lbs drop height (in)	50	50	50
Hail Energy Ref. (in-lbs)	0.83	13.3	124.9

7.2.2 Attaching Protective Skins to Base Panels

The protective skins are all designed to be attached to the base substrate panel with double-sided tape. The open issue for the impact panels was whether or not the protective backing could be left on the tape so that the protective skin would not be attached to the substrate panel. The reason to do this is to make it easier to inspect the side of the substrate panel next to the protective skin.

To provide the data necessary to make a decision, two small sample panels were provided: one with the protective skin stuck to the substrate and one with the backing remaining on the tape and the protective skin not attached to the substrate panel. Identical impacts were made on both panels. Visual results are shown in Figure 44 for the panel with the protective skin adhered to the substrate panel and in Figure 45 for the protective skin not adhered to the panel. Thermographic results are shown in Figure 46 for the protective skin adhered to the substrate panel and in Figure 47 for the protective skin not adhered to the substrate panel. Thermographic inspection worked well for both conditions.

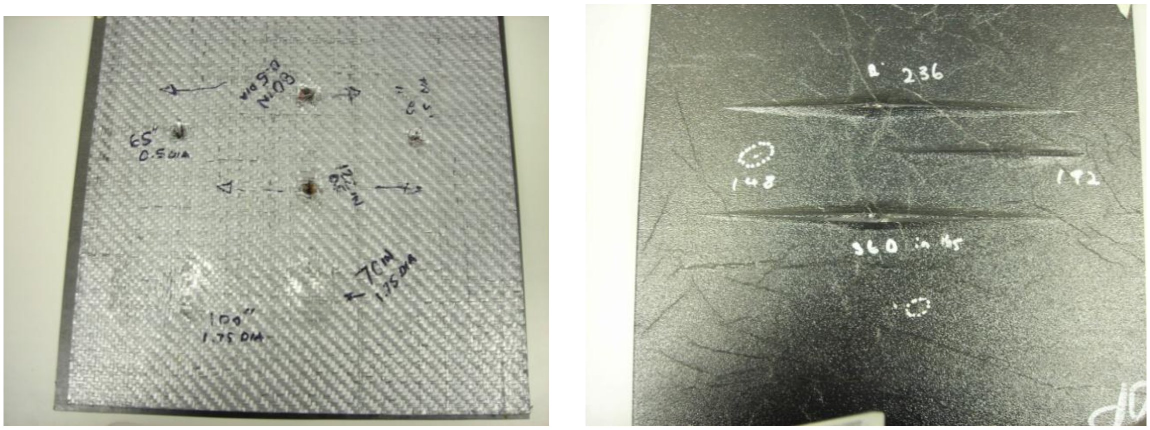


Figure 44: Front and back visual views of impact panel with protective skin adhered to substrate panel.

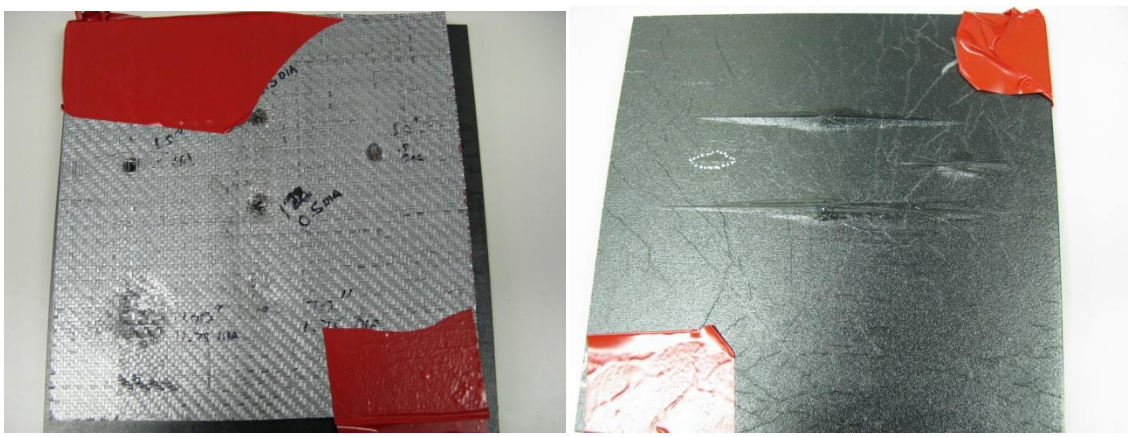
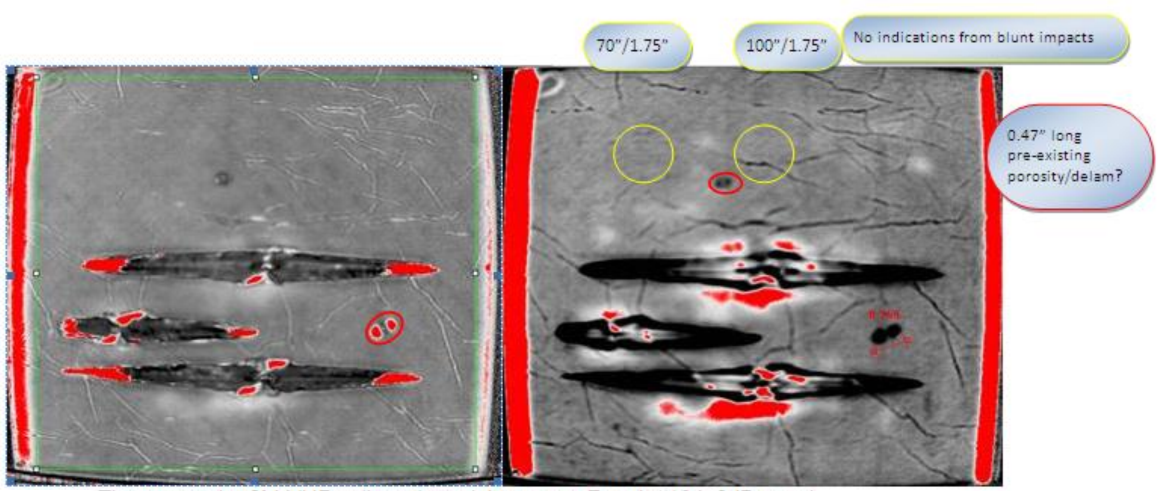


Figure 45: Front and back visual views of impact panel with protective skin not adhered to substrate panel.



Thermography 3M VHB *adhered* top-right quarter Panel #104. 3dB panel
(Peak Ampl.- Pos. 2nd Derv. & 1st Derv. - 0.94 sec).

Figure 46: Thermography results for protective skin adhered to substrate panel.

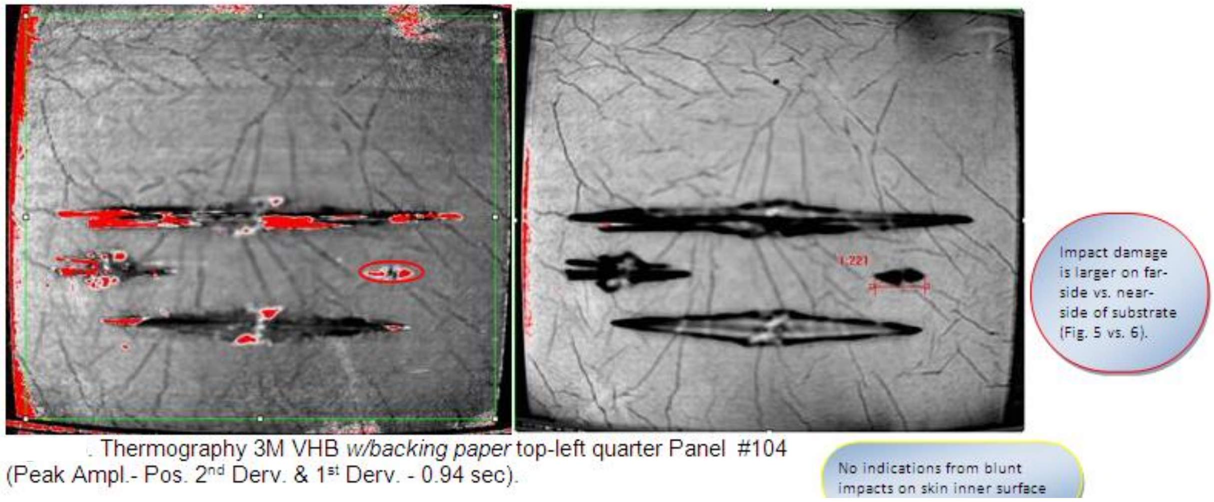


Figure 47: Thermography results for protective skin not adhered to substrate panel.

It was much easier to visually inspect the damage on the inner surface of the substrate (next to the protective skin) when the protective skin was not adhered to the surface of the substrate. It was also possible to use thermography to inspect from the "inner" (tool side) of the substrate when the protective skin was not adhered to the base substrate (see Figure 48). For this reason, the supplier was asked to not attach the impact test articles to the substrate. Nineteen impact test articles were built before this request was made and comprehended. Those test articles were be used as is for this round of testing.

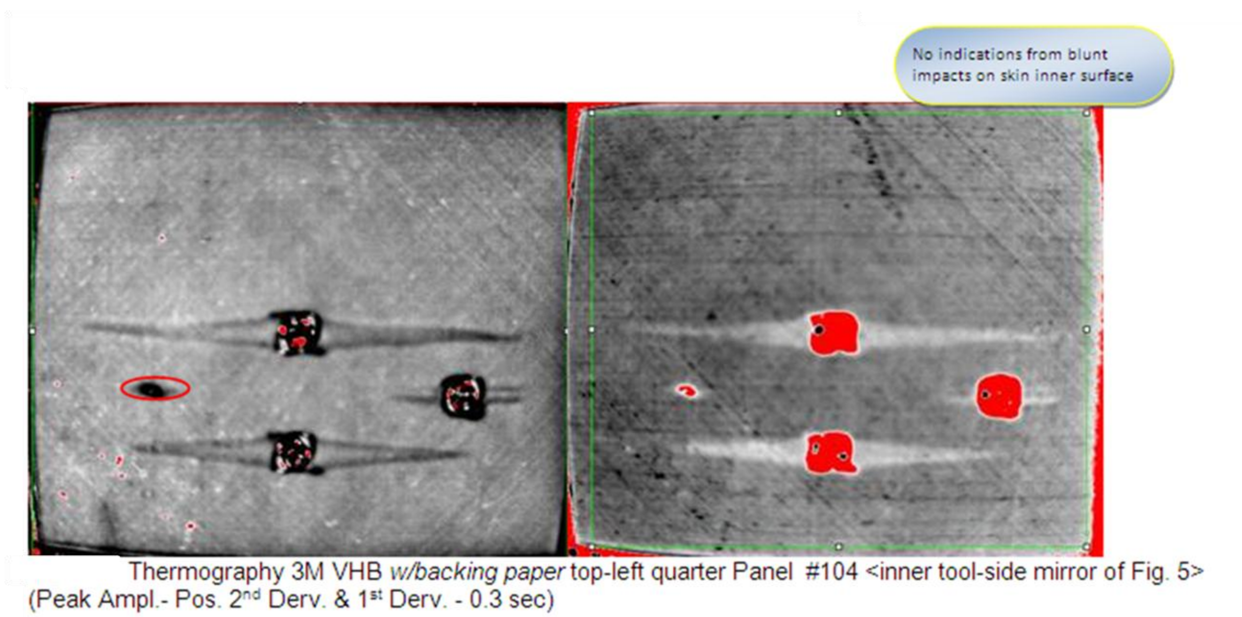


Figure 48: Thermography result for "inner" side of substrate not adhered to substrate panel.

One other interesting thing was learned from this trial testing. The damage from the impacts ran in the direction of the fibers on the inner and outer layer (0° orientation as shown in Figure 29). The impact test fixture layout has three bays as shown in Figure 49.

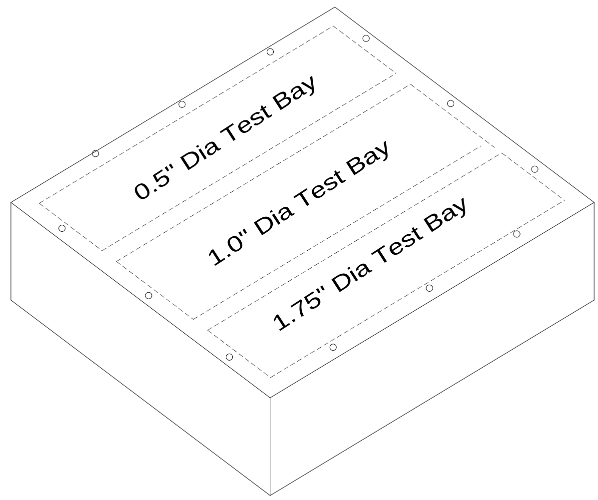


Figure 49: Impact test fixture test bay definition.

There were three impacts per test bay initially. If the panel is oriented such that the inner and outer layers of fibers run parallel to the long direction of the test bays, the impacts interfered with each other as the fibers split. If the inner and outer layer of fibers run parallel to the short direction of the test bays, the test fixture clamps help stop the damage from running beyond the edge of the test bay. The mounting hole pattern was modified to include this instruction to the supplier (see Figure 50).

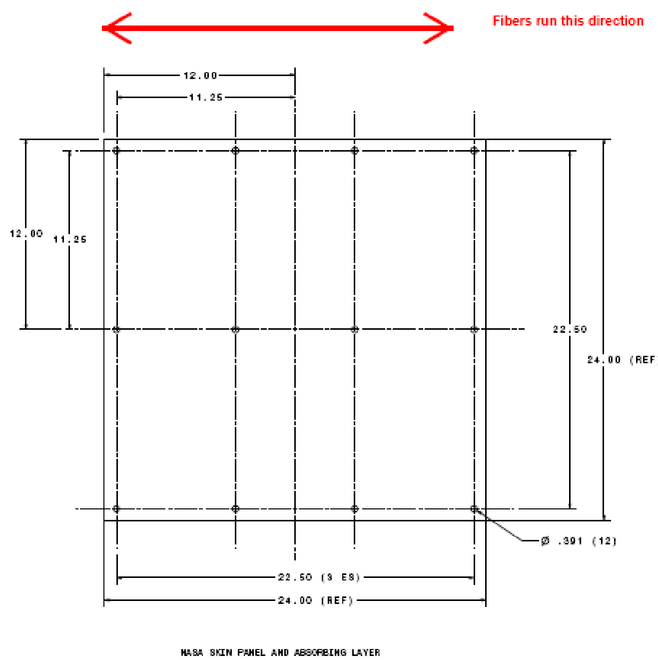


Figure 50: Impact test article mounting hole definition.

7.2.3 Impact Test Facility

A fixture to expedite testing was designed and constructed. Each test article is impacted by three impactors of three different diameters at three different energy levels. Each test article is divided into three bays (one for each impactor) as was shown in the drawing in Figure 49. A picture of the actual bays of the test article support fixture are shown from underneath with a test article mounted in Figure 50**.** A side view of a test article is shown mounted on the drop test support fixture in Figure 52. The drop test support fixture is shown mounted in the drop test facility in Figure 53.

Constant weight impactors with the three diameters (0.5”, 1.0”, and 1.75”) were manufactured to use in the test facility. The test fixture will allow three strikes at one energy level (constant height) by the three different impactor diameters (see Figure 54 for the drawing and Figure 55 for a picture). The impactors’ guide tubes have holes and pins at the three required heights. Each impactor is attached to a cable by an electromagnet. In preparation for testing, one impactor is placed in the tube and allowed to rest on the pin. The pin is removed, the electromagnet is turned off, and the impactor drops. A board (as shown in green in Figure 53) is placed in the test bay and is slid over the impact site as soon as the impact happens. The board protects the impact site from secondary impacts.

Figure 51: Underneath view of test bay with panel IM-32 mounted.

Figure 52: Panel IM-100 installed on drop test support fixture.

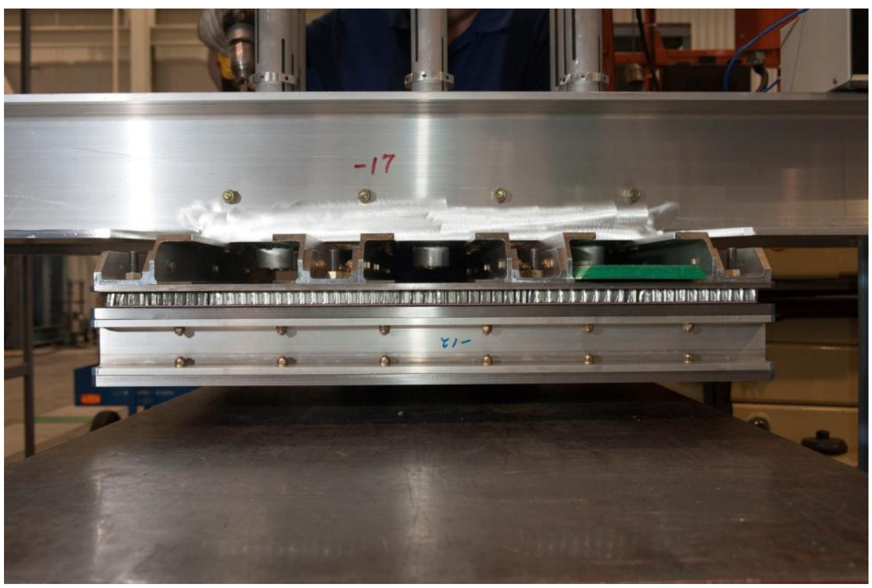


Figure 53: IM-62 installed in drop test support facility.

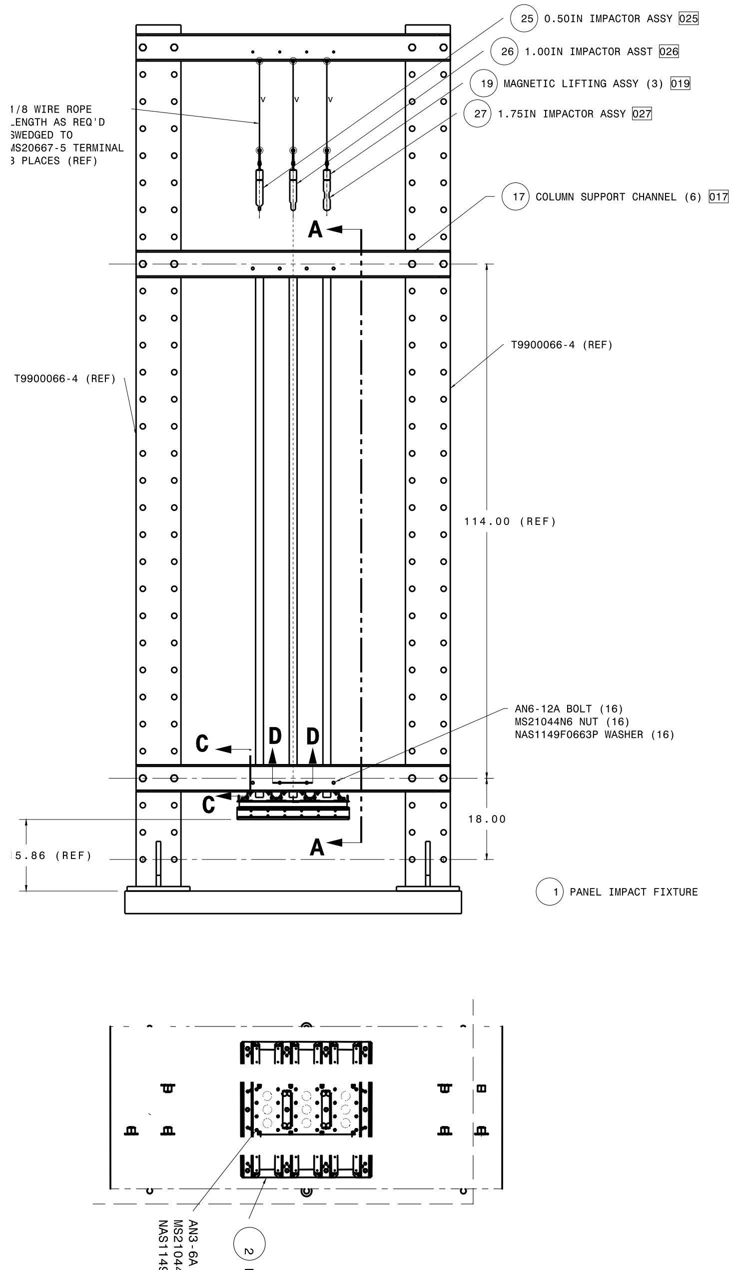


Figure 54: Impact Tube Test Fixture (side and top view).

Figure 55: Impact test fixture.

7.2.4 Test Objectives

Two criteria (as described in the previous section on Requirements) are important for the impact tests: 1) the amount of energy the panel is capable of absorbing; and 2) any damage which could affect ultimate

strength is visible. For the purposes of the impact test, the energy threshold levels for the following five classes of damage will be considered:

- Maximum energy to cause no damage to the protective skin or structure (substrate) below.
- Maximum energy to cause visible damage to the skin but no damage to the structure below.
- Maximum energy to cause hidden damage to the structure below.
- Maximum energy to cause visible damage to the structure below:
- When observed from the back (substrate) side of the test panel.
- When observed from the front (protective skin) side of the test panel.

These classes of damage can be related to the five FAA damage categories described in AC 20-107B (Reference 2) but do not align exactly. The goal of the STAR-C^2 protective skins will be to eliminate Class 3 and 4a damage.

7.2.5 Test Results

The 99 impact panels were tested by applying the nine impacts to each one (except for IM-100 which will be discussed later in this section). Pictures were taken of the front and back of each impact panel before and after impact testing. If features of interest were visible on the impact panel after testing, additional pictures of the features were taken. After impact testing was completed for each panel, thermographic inspection was conducted.

Panel IM-100 was mentioned as an exception to experiencing all nine impacts. The test panel installed in the text fixture base was shown in Figure 52. The aftermath of testing with the 0.5" impactor at 180 in-lbs is shown from the top side in Figure 56 and from the underneath side in Figure 57. The impactor embedded in the test panel and did not bounce up. No impact was made with the 0.5" impactor at 250 in-lbs because it is likely that the impactor would have gone completely through the test panel and impacted the block of foam underneath the test fixture.

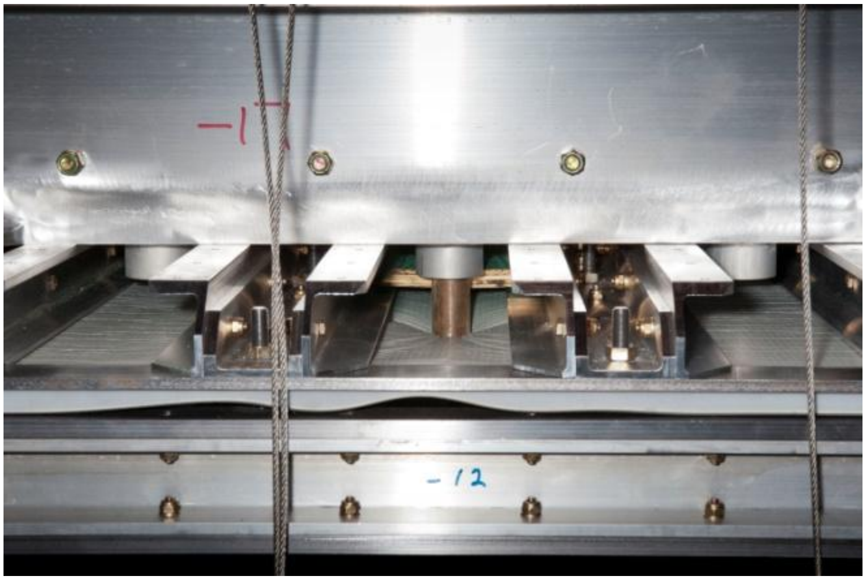


Figure 56: Top side view of IM-100 after impact.

Figure 57: Underneath view of IM-100 with 0.5" impactor embedded.

The data which was collected from the impacts on panel IM-100 came from the front and back views of the panel after impact (Figure 58). For reference, the initial ultrasonic inspection of IM-100 is shown in Figure 59. The thermographic inspection made after impacting is shown in Figure 60.

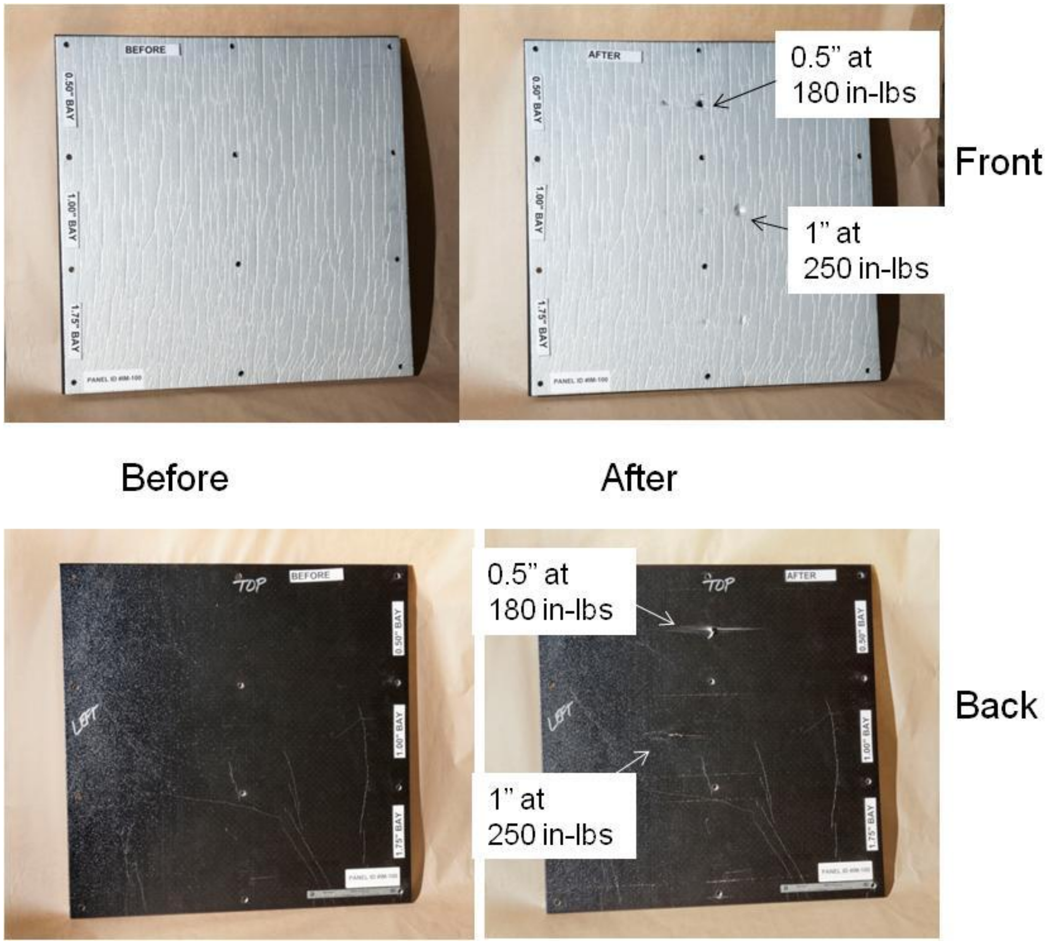


Figure 58: Before and after impact views of the front and back of IM-100.

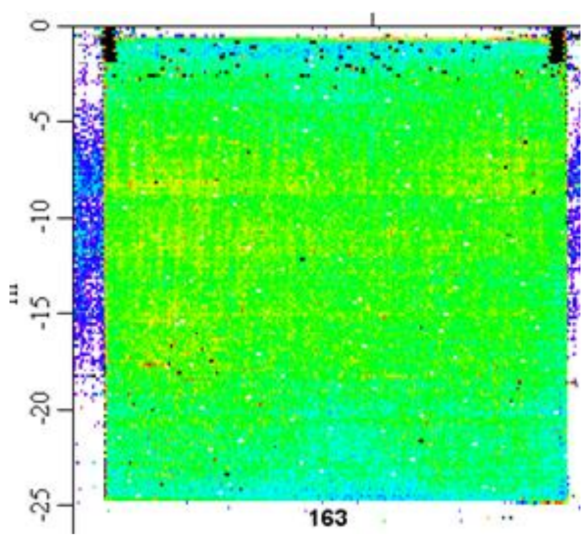


Figure 59: Initial ultrasonic inspection.

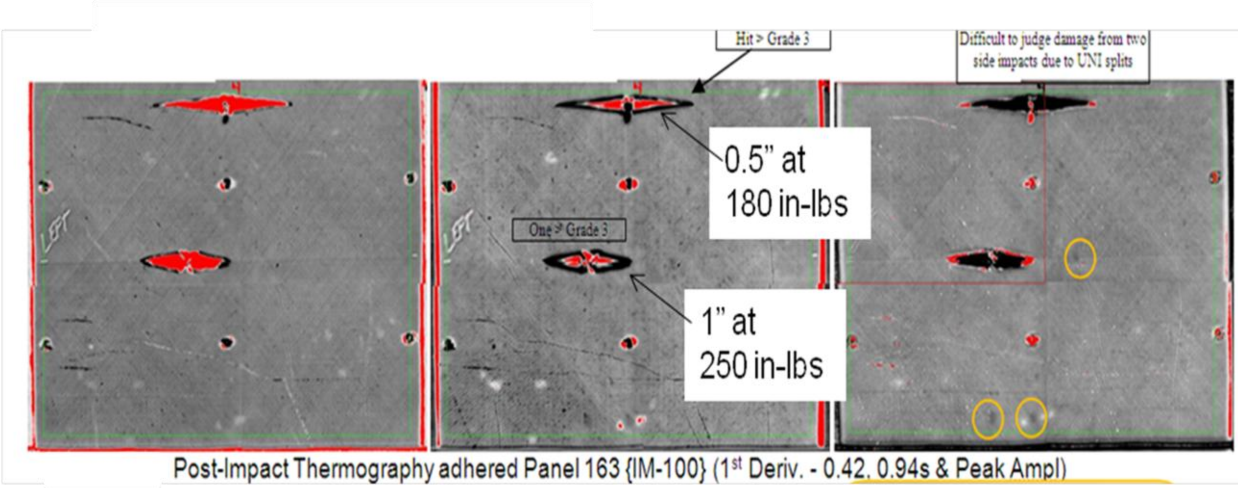


Figure 60: Thermographic inspection of IM-100.

The data was for every panel was collected in the same way that the data was collected for panel IM-100. The data for IM-100 is shown in Table 48. A description of the test data columns is presented in Table 49. There are nine lines of data for each test article. The first three are for the 0.5" impactor (shown in column 6) at 50, 180, and 250 in-lbs (shown in column 7); the next three are for the 1.0" impactor at the three energy levels; and the final three are for the 1.75" impactor at the three energy levels. The N/A's on line 3 show that the 0.5" impactor at 250 in-lbs test was not conducted.

Table 48 shows that IM-100 passed impact testing for 0.5" impactor at 50 in-lbs, 1.0" impactor at 50 and 180 in-lbs, and 1.75" impactor at 50, 180, and 250 in-lbs (the set of realistic conditions suggested earlier). There are no cases for IM-100 where visible damage is no and base panel damage is yes (which would violate the need to be able to visually detect actual damage).

Table 48 - Impact Test Data Collected for Panel IM-100

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	50	Y	A	N	Y
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	180	Y	E	Y	Y
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	250	N/A	N/A	N/A	N/A
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	50	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	180	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	250	Y	E	Y	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	50	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	180	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	250	Y	A	N	N

Table 49 - Description of Test Data Columns

Panel:	Test article number
Impact Absorbing Layer:	Material used for impact absorption (including nominal thickness)
Impact Spreading Layer:	Material used to spread impact (if present)
Protective Skin psf:	Calculated protective skin areal weight in pound per square foot. Protective skin weight found by substrating base panel weight from test article weight.
Total Weight:	Measured weight of the impact panel.
Visible Damage:	Visible at 5 feet by untrained personnel (Category 3).
NDI Disposition:	Base panel damage area measured by Thermography. A=0.000 to 0.062 sq. in., B=0.063 to 0.25 sq. in., C=>0.25 to 0.56 sq. in., D=>0.56 to 1.00 sq. in., E=>1.00 sq.in. (Catecoy C, D, and E are failures.)
Base Panel Damage:	Visible damage to base (structural panel)
Penetration (>75%):	Protective skin penetration measured with depth gauge, "Y" if greater than 75% penetration.

All of the test article impact data collected is shown in Table 50. The thermographic inspection pictures can be found in Appendix C, and the supporting before and after pictures can be found in Appendix D – First-Generation Test Article Impact Testing Pictures.

Table 50 - Impact Test Data (1 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Dispostion	Base Panel Damage	Penetration (>75%)
IM-1	None	None	0.000	1.30	0.50	50	N	D	Y	N/A
IM-1	None	None	0.000	1.30	0.50	180	Y	E	Y	N/A
IM-1	None	None	0.000	1.30	0.50	250	Y	E	Y	N/A
IM-1	None	None	0.000	1.30	1.00	50	N	C	Y	N/A
IM-1	None	None	0.000	1.30	1.00	180	Y	E	Y	N/A
IM-1	None	None	0.000	1.30	1.00	250	Y	E	Y	N/A
IM-1	None	None	0.000	1.30	1.75	50	N	C	N	N/A
IM-1	None	None	0.000	1.30	1.75	180	Y	E	Y	N/A
IM-1	None	None	0.000	1.30	1.75	250	Y	E	Y	N/A
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	0.50	50	Y	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	0.50	180	Y	E	Y	Y
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	0.50	250	Y	E	Y	Y
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.00	50	N	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.00	180	Y	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.00	250	Y	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.75	50	N	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.75	180	N	A	N	N
IM-2	10# PU core, 1/4" T	Carbon epoxy	0.536	3.49	1.75	250	N	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	0.50	50	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	0.50	180	Y	D	Y	Y
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	0.50	250	Y	E	Y	Y
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.00	50	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.00	180	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.00	250	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.75	50	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.75	180	Y	A	N	N
IM-3	10# PU core, 1/4" T	Innegra	0.475	3.22	1.75	250	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	0.50	50	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	0.50	180	Y	A	N	Y
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	0.50	250	Y	E	Y	Y
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.00	50	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.00	180	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.00	250	Y	A	N	Y
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.75	50	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.75	180	Y	A	N	N
IM-4	10# PU core, 1/4" T	0.012" alum	0.634	3.88	1.75	250	Y	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	0.50	50	Y	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	0.50	180	Y	E	Y	Y
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	0.50	250	Y	E	Y	Y
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.00	50	Y	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.00	180	N	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.00	250	Y	A	N	Y
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.75	50	N	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.75	180	Y	A	N	N
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	3.21	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (2 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	0.50	50	Y	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	0.50	180	Y	A	N	Y
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	0.50	250	Y	E	Y	Y
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.00	50	N	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.00	180	Y	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.00	250	Y	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.75	50	N	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.75	180	N	A	N	N
IM-6	10# PU core, 1/2" T	Carbon epoxy	0.770	4.40	1.75	250	N	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	0.50	50	Y	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	0.50	180	Y	A	N	Y
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	0.50	250	Y	E	Y	Y
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.00	50	Y	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.00	180	Y	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.00	250	Y	A	N	Y
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.75	50	Y	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.75	180	Y	A	N	N
IM-7	10# PU core, 1/2" T	Innegra	0.695	4.12	1.75	250	Y	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	0.50	50	Y	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	0.50	180	Y	A	N	Y
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	0.50	250	Y	E	Y	Y
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.00	50	N	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.00	180	N	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.00	250	Y	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.75	50	N	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.75	180	N	A	N	N
IM-8	10# PU core, 1/2" T	Tegris LM	0.684	4.06	1.75	250	Y	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	0.50	50	Y	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	0.50	180	Y	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	0.50	250	Y	A	N	Y
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.00	50	N	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.00	180	Y	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.00	250	Y	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.75	50	N	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.75	180	N	A	N	N
IM-9	10# PU core, 3/4" T	Carbon epoxy	0.948	5.15	1.75	250	N	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	0.50	50	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	0.50	180	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	0.50	250	Y	A	N	Y
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.00	50	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.00	180	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.00	250	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.75	50	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.75	180	Y	A	N	N
IM-10	10# PU core, 3/4" T	Innegra	0.890	4.90	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (3 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	0.50	50	Y	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	0.50	180	Y	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	0.50	250	Y	A	N	Y
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.00	50	N	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.00	180	N	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.00	250	Y	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.75	50	N	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.75	180	N	A	N	N
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	4.73	1.75	250	Y	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	0.50	50	Y	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	0.50	180	Y	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	0.50	250	Y	A	N	Y
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.00	50	N	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.00	180	Y	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.00	250	Y	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.75	50	N	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.75	180	N	A	N	N
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	5.95	1.75	250	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	0.50	50	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	0.50	180	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	0.50	250	Y	A	N	Y
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.00	50	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.00	180	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.00	250	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.75	50	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.75	180	Y	A	N	N
IM-13	10# PU core, 1" T	Innegra	1.100	5.75	1.75	250	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	0.50	50	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	0.50	180	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	0.50	250	Y	A	N	Y
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.00	50	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.00	180	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.00	250	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.75	50	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.75	180	Y	A	N	N
IM-14	10# PU core, 1" T	0.012" alum	1.233	6.25	1.75	250	Y	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	0.50	50	Y	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	0.50	180	Y	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	0.50	250	Y	A	N	Y
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.00	50	N	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.00	180	N	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.00	250	Y	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.75	50	Y	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.75	180	N	A	N	N
IM-15	10# PU core, 1" T	Tegris LM	1.095	5.70	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (4 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	0.50	50	Y	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	0.50	180	Y	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	0.50	250	Y	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.00	50	N	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.00	180	Y	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.00	250	Y	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.75	50	N	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.75	180	N	A	N	N
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	4.24	1.75	250	N	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	0.50	50	Y	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	0.50	180	Y	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	0.50	250	Y	D	Y	Y
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.00	50	N	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.00	180	Y	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.00	250	Y	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.75	50	N	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.75	180	N	A	N	N
IM-17	20# PU core, 1/4" T	Innegra	0.670	4.02	1.75	250	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	0.50	50	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	0.50	180	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	0.50	250	Y	A	N	Y
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.00	50	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.00	180	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.00	250	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.75	50	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.75	180	Y	A	N	N
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	4.58	1.75	250	Y	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	0.50	50	N	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	0.50	180	Y	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	0.50	250	Y	D	Y	Y
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.00	50	N	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.00	180	N	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.00	250	Y	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.75	50	N	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.75	180	N	A	N	N
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	4.03	1.75	250	Y	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	0.50	50	Y	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	0.50	180	Y	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	0.50	250	Y	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.00	50	N	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.00	180	N	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.00	250	Y	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.75	50	N	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.75	180	N	A	N	N
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	5.85	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (5 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	0.50	50	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	0.50	180	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	0.50	250	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.00	50	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.00	180	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.00	250	Y	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.75	50	N	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.75	180	N	A	N	N
IM-21	20# PU core, 1/2" T	Innegra	1.065	5.60	1.75	250	Y	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	0.50	50	N	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	0.50	180	Y	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	0.50	250	Y	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.00	50	N	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.00	180	N	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.00	250	Y	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.75	50	N	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.75	180	N	A	N	N
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	5.65	1.75	250	N	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	0.50	50	Y	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	0.50	180	Y	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	0.50	250	Y	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.00	50	N	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.00	180	Y	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.00	250	Y	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.75	50	N	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.75	180	N	A	N	N
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	7.30	1.75	250	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	0.50	50	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	0.50	180	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	0.50	250	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.00	50	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.00	180	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.00	250	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.75	50	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.75	180	Y	A	N	N
IM-24	20# PU core, 3/4" T	Innegra	1.458	7.15	1.75	250	Y	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	0.50	50	Y	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	0.50	180	Y	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	0.50	250	Y	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.00	50	N	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.00	180	N	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.00	250	Y	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.75	50	N	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.75	180	N	A	N	N
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	7.20	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (6 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	0.50	50	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	0.50	180	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	0.50	250	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.00	50	N	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.00	180	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.00	250	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.75	50	N	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.75	180	Y	A	N	N
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	8.95	1.75	250	Y	A	N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	0.50	50	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	0.50	180	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	0.50	250	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.00	50	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.00	180	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.00	250	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.75	50	N		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.75	180	Y		N	N
IM-27	20# PU core, 1" T	Innegra	1.833	8.65	1.75	250	Y		N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	0.50	50	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	0.50	180	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	0.50	250	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.00	50	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.00	180	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.00	250	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.75	50	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.75	180	Y	A	N	N
IM-28	20# PU core, 1" T	0.012" alum	2.005	9.35	1.75	250	Y	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	0.50	50	Y	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	0.50	180	Y	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	0.50	250	Y	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.00	50	N	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.00	180	N	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.00	250	Y	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.75	50	N	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.75	180	N	A	N	N
IM-29	20# PU core, 1" T	Tegris LM	1.928	9.05	1.75	250	Y	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	0.50	50	N	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	0.50	180	Y	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	0.50	250	Y	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.00	50	N	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.00	180	Y	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.00	250	Y	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.75	50	N	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.75	180	N	A	N	N
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	5.05	1.75	250	N	A	N	N

Table 50 - Impact Test Data (7 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	0.50	50	N	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	0.50	180	Y	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	0.50	250	Y	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.00	50	N	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.00	180	N	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.00	250	Y	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.75	50	N	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.75	180	N	A	N	N
IM-31	30# PU core, 1/4" T	Innegra	0.866	4.81	1.75	250	N	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	0.50	50	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	0.50	180	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	0.50	250	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.00	50	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.00	180	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.00	250	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.75	50	N	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.75	180	Y	A	N	N
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	5.35	1.75	250	Y	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	0.50	50	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	0.50	180	Y	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	0.50	250	Y	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.00	50	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.00	180	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.00	250	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.75	50	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.75	180	N	A	N	N
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	4.81	1.75	250	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	0.50	50	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	0.50	180	Y	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	0.50	250	Y	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.00	50	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.00	180	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.00	250	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.75	50	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.75	180	N	A	N	N
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	7.45	1.75	250	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	0.50	50	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	0.50	180	Y	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	0.50	250	Y	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.00	50	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.00	180	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.00	250	Y	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.75	50	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.75	180	N	A	N	N
IM-35	30# PU core, 1/2" T	Innegra	1.475	7.20	1.75	250	N	A	N	N

Table 50 - Impact Test Data (8 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	0.50	50	N	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	0.50	180	Y	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	0.50	250	Y	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.00	50	N	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.00	180	N	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.00	250	Y	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.75	50	N	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.75	180	N	A	N	N
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	7.20	1.75	250	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	0.50	50	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	0.50	180	Y	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	0.50	250	Y	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.00	50	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.00	180	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.00	250	Y	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.75	50	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.75	180	N	A	N	N
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	9.85	1.75	250	N	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	0.50	50	Y	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	0.50	180	Y	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	0.50	250	Y	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.00	50	N	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.00	180	Y	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.00	250	Y	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.75	50	N	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.75	180	N	A	N	N
IM-38	30# PU core, 3/4" thick	Innegra	2.075	9.60	1.75	250	Y	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	0.50	50	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	0.50	180	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	0.50	250	Y	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.00	50	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.00	180	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.00	250	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.75	50	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.75	180	N	A	N	N
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	9.55	1.75	250	N	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	0.50	50	Y	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	0.50	180	Y	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	0.50	250	Y	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.00	50	N	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.00	180	Y	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.00	250	Y	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.75	50	N	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.75	180	N	A	N	N
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	12.30	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (9 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	0.50	50	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	0.50	180	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	0.50	250	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.00	50	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.00	180	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.00	250	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.75	50	N	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.75	180	Y	A	N	N
IM-41	30# PU core, 1" T	Innegra	2.658	11.95	1.75	250	Y	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	0.50	50	N	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	0.50	180	Y	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	0.50	250	Y	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.00	50	N	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.00	180	N	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.00	250	Y	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.75	50	N	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.75	180	N	A	N	N
IM-43	30# PU core, 1" T	Tegris LM	2.670	12.00	1.75	250	N	A	N	N
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	0.50	50	Y	A	N	Y
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	0.50	180	Y	E	Y	Y
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	0.50	250	Y	E	Y	Y
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.00	50	N	A	N	N
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.00	180	Y	A	N	N
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.00	250	Y	A	N	Y
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.75	50	N	A	N	N
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.75	180	Y	A	N	N
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	3.28	1.75	250	Y	A	N	N
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	0.50	50	Y	A	N	Y
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	0.50	180	Y	E	N	Y
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	0.50	250	Y	E	Y	Y
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.00	50	Y	A	N	N
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.00	180	Y	A	N	Y
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.00	250	Y	A	N	Y
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.75	50	Y	A	N	N
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.75	180	Y	A	N	N
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	2.95	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (10 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	0.50	50	Y	A	N	N
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	0.50	180	Y	E	Y	Y
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	0.50	250	Y	E	Y	Y
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.00	50	Y	A	N	N
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.00	180	Y	A	N	Y
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.00	250	Y	A	N	Y
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.75	50	Y	A	N	N
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.75	180	Y	A	N	N
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	3.50	1.75	250	Y	A	N	Y
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	0.50	50	Y	A	N	Y
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	0.50	180	Y	E	Y	Y
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	0.50	250	Y	E	Y	Y
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.00	50	Y	A	N	N
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.00	180	Y	A	N	N
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.00	250	Y	A	N	Y
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.75	50	N	A	N	N
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.75	180	N	A	N	N
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	2.98	1.75	250	Y	A	N	N
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	0.50	50	Y	A	N	Y
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	0.50	180	Y	E	Y	Y
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	0.50	250	Y	E	Y	Y
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.00	50	N	A	N	N
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.00	180	Y	A	N	Y
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.00	250	Y	A	N	Y
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.75	50	Y	A	N	N
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.75	180	Y	A	N	N
IM-48	3 pcf Al H/C, 1/2" T	Carbon epoxy	0.565	3.58	1.75	250	Y	A	N	N
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	0.50	50	Y	A	N	N
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	0.50	180	Y	E	Y	Y
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	0.50	250	Y	E	Y	Y
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.00	50	Y	A	N	N
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.00	180	Y	A	N	Y
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.00	250	Y	A	N	Y
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.75	50	Y	A	N	N
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.75	180	Y	A	N	N
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	3.27	1.75	250	Y	A	N	N
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	0.50	50	Y	A	N	Y
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	0.50	180	Y	E	Y	Y
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	0.50	250	Y	E	Y	Y
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.00	50	Y	A	N	N
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.00	180	Y	A	N	Y
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.00	250	Y	A	N	Y
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.75	50	Y	A	N	N
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.75	180	Y	A	N	N
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	3.47	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (11 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	0.50	50	Y	A	N	Y
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	0.50	180	Y	E	Y	Y
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	0.50	250	Y	E	Y	Y
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.00	50	N	A	N	N
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.00	180	Y	A	N	Y
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.00	250	Y	A	N	Y
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.75	50	N	A	N	N
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.75	180	Y	A	N	N
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	3.78	1.75	250	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	0.50	50	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	0.50	180	Y	E	Y	Y
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	0.50	250	Y	E	Y	Y
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.00	50	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.00	180	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.00	250	Y	A	N	Y
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.75	50	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.75	180	Y	A	N	N
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	3.55	1.75	250	Y	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	0.50	50	Y	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	0.50	180	Y	E	Y	Y
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	0.50	250	Y	E	Y	Y
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.00	50	Y	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.00	180	Y	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.00	250	Y	A	N	Y
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.75	50	N	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.75	180	Y	A	N	N
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	3.65	1.75	250	Y	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	0.50	50	Y	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	0.50	180	Y	C	N	Y
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	0.50	250	Y	E	Y	Y
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.00	50	Y	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.00	180	Y	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.00	250	Y	A	N	Y
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.75	50	N	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.75	180	Y	A	N	N
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	4.09	1.75	250	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	0.50	50	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	0.50	180	Y	A	N	Y
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	0.50	250	Y	E	Y	Y
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.00	50	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.00	180	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.00	250	Y	A	N	Y
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.75	50	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.75	180	Y	A	N	N
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	3.81	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (12 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	0.50	50	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	0.50	180	Y	B	N	Y
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	0.50	250	Y	D	Y	Y
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.00	50	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.00	180	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.00	250	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.75	50	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.75	180	Y	A	N	N
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	4.38	1.75	250	Y	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	0.50	50	Y	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	0.50	180	Y	E	Y	Y
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	0.50	250	Y	E	Y	Y
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.00	50	Y	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.00	180	Y	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.00	250	Y	A	N	Y
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.75	50	N	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.75	180	Y	A	N	N
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	3.81	1.75	250	Y	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	0.50	50	Y	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	0.50	180	Y	E	N	Y
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	0.50	250	Y	E	Y	Y
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.00	50	N	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.00	180	Y	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.00	250	Y	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.75	50	N	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.75	180	N	A	N	N
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	3.49	1.75	250	Y	A	N	N
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	0.50	50	Y	A	N	Y
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	0.50	180	Y	C	Y	Y
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	0.50	250	Y	E	Y	Y
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.00	50	Y	A	N	N
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.00	180	Y	A	N	Y
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.00	250	Y	D	Y	Y
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.75	50	Y	A	N	N
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.75	180	Y	A	N	N
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	3.26	1.75	250	Y	A	N	N
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	0.50	50	Y	A	N	N
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	0.50	180	Y	C	N	Y
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	0.50	250	Y	E	Y	Y
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.00	50	Y	A	N	N
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.00	180	Y	A	N	Y
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.00	250	Y	A	N	Y
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.75	50	Y	A	N	N
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.75	180	Y	A	N	N
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	3.85	1.75	250	Y	A	N	Y

Table 50 - Impact Test Data (13 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	0.50	50	Y	A	N	Y
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	0.50	180	Y	E	Y	Y
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	0.50	250	Y	E	Y	Y
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.00	50	N	A	N	N
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.00	180	Y	A	N	Y
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.00	250	Y	A	N	Y
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.75	50	N	A	N	N
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.75	180	N	A	N	N
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	3.22	1.75	250	Y	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	0.50	50	Y	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	0.50	180	Y	E	Y	Y
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	0.50	250	Y	E	Y	Y
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.00	50	N	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.00	180	Y	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.00	250	Y	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.75	50	N	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.75	180	Y	A	N	N
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	3.97	1.75	250	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	0.50	50	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	0.50	180	Y	E	Y	Y
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	0.50	250	Y	E	Y	Y
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.00	50	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.00	180	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.00	250	Y	A	N	Y
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.75	50	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.75	180	Y	A	N	N
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	3.78	1.75	250	Y	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	0.50	50	Y	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	0.50	180	Y	E	N	Y
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	0.50	250	Y	E	Y	Y
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.00	50	Y	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.00	180	Y	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.00	250	Y	A	N	Y
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.75	50	Y	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.75	180	N	A	N	N
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	3.78	1.75	250	Y	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	0.50	50	Y	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	0.50	180	Y	A	N	Y
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	0.50	250	Y	E	Y	Y
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.00	50	N	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.00	180	Y	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.00	250	Y	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.75	50	N	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.75	180	Y	A	N	N
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	4.60	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (14 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	0.50	50	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	0.50	180	Y	E	Y	Y
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	0.50	250	Y	E	Y	Y
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.00	50	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.00	180	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.00	250	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.75	50	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.75	180	Y	A	N	N
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	4.34	1.75	250	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	0.50	50	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	0.50	180	Y	E	Y	Y
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	0.50	250	Y	E	Y	Y
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.00	50	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.00	180	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.00	250	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.75	50	N	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.75	180	Y	A	N	N
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	4.40	1.75	250	Y	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	0.50	50	Y	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	0.50	180	Y	C	N	Y
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	0.50	250	Y	E	N	Y
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.00	50	N	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.00	180	Y	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.00	250	Y	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.75	50	N	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.75	180	Y	A	N	N
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	5.15	1.75	250	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	0.50	50	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	0.50	180	Y	A	N	Y
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	0.50	250	Y	A	N	Y
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.00	50	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.00	180	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.00	250	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.75	50	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.75	180	Y	A	N	N
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	4.84	1.75	250	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	0.50	50	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	0.50	180	Y	A	N	Y
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	0.50	250	Y	A	N	Y
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.00	50	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.00	180	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.00	250	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.75	50	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.75	180	Y	A	N	N
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	5.45	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (15 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	0.50	50	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	0.50	180	Y	A	N	Y
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	0.50	250	Y	E	Y	Y
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.00	50	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.00	180	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.00	250	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.75	50	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.75	180	Y	A	N	N
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	4.96	1.75	250	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	0.50	50	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	0.50	180	Y	E	Y	Y
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	0.50	250	Y	E	Y	Y
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.00	50	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.00	180	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.00	250	Y	A	N	Y
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.75	50	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.75	180	Y	A	N	N
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	3.64	1.75	250	Y	A	N	N
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	0.50	50	Y	A	N	N
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	0.50	180	Y	E	Y	Y
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	0.50	250	Y	E	Y	Y
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.00	50	Y	A	N	N
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.00	180	Y	A	N	Y
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.00	250	Y	A	N	Y
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.75	50	Y	A	N	N
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.75	180	Y	A	N	N
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	3.36	1.75	250	Y	A	N	N
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	0.50	50	Y	A	N	N
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	0.50	180	Y	B	N	Y
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	0.50	250	Y	E	Y	Y
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.00	50	Y	A	N	N
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.00	180	Y	A	N	Y
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.00	250	Y	A	N	Y
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.75	50	Y	A	N	N
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.75	180	Y	A	N	N
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	3.84	1.75	250	Y	A	N	N
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	0.50	50	Y	A	N	Y
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	0.50	180	Y	E	Y	Y
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	0.50	250	Y	E	Y	Y
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.00	50	N	A	N	N
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.00	180	Y	A	N	Y
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.00	250	Y	A	N	Y
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.75	50	N	A	N	N
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.75	180	Y	A	N	N
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	3.35	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (16 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	0.50	50	Y	A	N	N
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	0.50	180	Y	E	Y	Y
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	0.50	250	Y	E	Y	Y
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.00	50	N	A	N	N
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.00	180	Y	A	N	N
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.00	250	Y	A	N	Y
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.75	50	N	A	N	N
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.75	180	Y	A	N	N
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	4.26	1.75	250	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	0.50	50	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	0.50	180	Y	C	N	Y
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	0.50	250	Y	E	Y	Y
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.00	50	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.00	180	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.00	250	Y	A	N	Y
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.75	50	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.75	180	Y	A	N	N
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	3.98	1.75	250	Y	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	0.50	50	Y	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	0.50	180	Y	E	Y	Y
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	0.50	250	Y	E	Y	Y
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.00	50	N	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.00	180	Y	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.00	250	Y	A	N	Y
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.75	50	N	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.75	180	Y	A	N	N
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	3.91	1.75	250	Y	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	0.50	50	Y	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	0.50	180	Y	C	N	Y
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	0.50	250	Y	E	Y	Y
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.00	50	N	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.00	180	Y	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.00	250	Y	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.75	50	N	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.75	180	Y	A	N	N
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	4.80	1.75	250	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	0.50	50	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	0.50	180	Y	C	N	Y
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	0.50	250	Y	E	Y	Y
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.00	50	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.00	180	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.00	250	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.75	50	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.75	180	Y	A	N	N
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	4.51	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (17 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	0.50	50	Y	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	0.50	180	Y	E	Y	Y
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	0.50	250	Y	E	Y	Y
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.00	50	N	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.00	180	Y	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.00	250	Y	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.75	50	Y	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.75	180	Y	A	N	N
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	4.56	1.75	250	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	0.50	50	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	0.50	180	Y	A	N	Y
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	0.50	250	Y	A	N	Y
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.00	50	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.00	180	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.00	250	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.75	50	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.75	180	Y	A	N	N
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	5.50	1.75	250	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	0.50	50	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	0.50	180	Y	A	N	Y
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	0.50	250	Y	A	N	Y
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.00	50	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.00	180	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.00	250	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.75	50	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.75	180	Y	A	N	N
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	5.20	1.75	250	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	0.50	50	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	0.50	180	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	0.50	250	Y	A	N	Y
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.00	50	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.00	180	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.00	250	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.75	50	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.75	180	Y	A	N	N
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	5.70	1.75	250	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	0.50	50	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	0.50	180	Y	A	N	Y
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	0.50	250	Y	A	N	Y
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.00	50	N	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.00	180	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.00	250	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.75	50	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.75	180	Y	A	N	N
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	5.25	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (18 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	0.50	50	Y	A	N	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	0.50	180	Y	D	Y	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	0.50	250	Y	E	Y	Y
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.00	50	N	A	N	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.00	180	Y	A	Y	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.00	250	Y	E	Y	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.75	50	N	A	N	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.75	180	N	A	N	N
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	2.90	1.75	250	N	A	N	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	0.50	50	N	A	N	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	0.50	180	Y	E	Y	Y
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	0.50	250	Y	E	Y	Y
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.00	50	N	A	N	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.00	180	Y	D	Y	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.00	250	Y	E	Y	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.75	50	N	A	N	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.75	180	N	D	Y	N
IM-87	Soric LRC, 2mm T	Innegra	0.328	2.63	1.75	250	N	D	Y	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	0.50	50	Y	A	N	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	0.50	180	Y	E	Y	Y
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	0.50	250	Y	E	Y	Y
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.00	50	N	A	N	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.00	180	N	E	Y	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.00	250	Y	E	Y	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.75	50	N	A	N	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.75	180	N	A	N	N
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	2.55	1.75	250	N	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	0.50	50	Y	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	0.50	180	Y	E	Y	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	0.50	250	Y	E	Y	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.00	50	N	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.00	180	Y	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.00	250	Y	E	Y	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.75	50	N	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.75	180	N	A	N	N
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	2.89	1.75	250	N	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	0.50	50	N	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	0.50	180	Y	E	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	0.50	250	Y	E	Y	Y
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.00	50	N	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.00	180	Y	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.00	250	Y	E	Y	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.75	50	N	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.75	180	Y	A	N	N
IM-90	Soric LRC, 3mm T	Innegra	0.310	2.58	1.75	250	Y	A	N	N

Table 50 - Impact Test Data (19 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	0.50	50	Y	A	N	N
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	0.50	180	Y	E	Y	Y
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	0.50	250	Y	E	Y	Y
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.00	50	Y	A	N	N
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.00	180	Y	A	N	Y
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.00	250	Y	A	N	Y
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.75	50	Y	A	N	N
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.75	180	Y	A	N	N
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	3.40	1.75	250	Y	A	N	Y
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	0.50	50	Y	A	N	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	0.50	180	Y	E	Y	Y
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	0.50	250	Y	E	Y	Y
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.00	50	N	A	N	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.00	180	N	A	N	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.00	250	Y	E	Y	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.75	50	N	A	N	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.75	180	N	A	N	N
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	2.57	1.75	250	N	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	0.50	50	Y	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	0.50	180	Y	E	Y	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	0.50	250	Y	E	Y	Y
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.00	50	N	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.00	180	Y	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.00	250	Y	E	Y	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.75	50	N	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.75	180	N	A	N	N
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	2.85	1.75	250	N	A	N	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	0.50	50	N	A	N	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	0.50	180	Y	E	Y	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	0.50	250	Y	E	Y	Y
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.00	50	N	A	N	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.00	180	Y	E	Y	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.00	250	Y	E	Y	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.75	50	N	A	N	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.75	180	N	A	N	N
IM-94	Soric XF, 2mm T	Innegra	0.296	2.52	1.75	250	Y	A	N	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	0.50	50	N	A	N	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	0.50	180	Y	E	Y	Y
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	0.50	250	Y	E	Y	Y
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.00	50	N	A	N	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.00	180	N	D	Y	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.00	250	Y	E	Y	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.75	50	N	A	N	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.75	180	N	D	Y	N
IM-95	Soric XF, 2mm T	Tegris LM	0.328	2.63	1.75	250	N	E	Y	N

Table 50 - Impact Test Data (20 of 20)

Panel	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	Total Weight	Impactor Dia	IN-LBS	Visible Damage	NDI Disposition	Base Panel Damage	Penetration (>75%)
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	0.50	50	Y	A	N	N
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	0.50	180	Y	E	Y	Y
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	0.50	250	Y	E	Y	Y
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.00	50	N	A	N	N
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.00	180	Y	A	N	N
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.00	250	Y	A	N	Y
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.75	50	N	A	N	N
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.75	180	N	A	N	N
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	3.03	1.75	250	N	A	N	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	0.50	50	Y	A	N	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	0.50	180	Y	E	Y	Y
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	0.50	250	Y	E	Y	Y
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.00	50	N	A	N	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.00	180	Y	D	Y	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.00	250	Y	E	Y	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.75	50	N	A	N	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.75	180	Y	A	N	N
IM-97	Soric XF, 6mm T	Innegra	0.351	2.73	1.75	250	Y	A	N	N
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	0.50	50	Y	A	N	Y
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	0.50	180	Y	D	Y	Y
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	0.50	250	Y	E	Y	Y
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.00	50	Y	A	N	N
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.00	180	Y	A	N	Y
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.00	250	Y	A	N	Y
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.75	50	Y	A	N	N
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.75	180	Y	A	N	N
IM-98	Soric XF, 6mm T	0.012" alum	0.469	3.18	1.75	250	Y	A	N	Y
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	0.50	50	Y	A	N	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	0.50	180	Y	E	Y	Y
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	0.50	250	Y	E	Y	Y
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.00	50	N	A	N	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.00	180	N	B	Y	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.00	250	Y	D	Y	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.75	50	N	A	N	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.75	180	Y	A	N	N
IM-99	Soric XF, 6mm T	Tegris LM	0.366	2.79	1.75	250	Y	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	50	Y	A	N	Y
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	180	Y	E	Y	Y
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	0.50	250	N/A	N/A	N/A	N/A
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	50	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	180	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.00	250	Y	E	Y	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	50	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	180	N	A	N	N
IM-100	PHM w/PEEK (3/4" T)	None	0.229	2.28	1.75	250	Y	A	N	N

7.2.6 Data Analysis

In order to start to make sense out of the data, the raw data in Table 50 was reorganized to have one line per impact panel with only the protective skin areal weight and the NDI rating for each impactor and each energy level as shown in Table 51. The "A", "B", "C", "D", and "E" NDI ratings were converted to numerical values "0", "1", "2", "3", and "4" where 0 corresponds to A (no damage) and 4 corresponds to E (maximum damage). The NDI ratings have been color coded to help visually inspect the data. The average NDI rating (sum of each NDI rating for a panel divided by 9) is also shown. An average NDI rating of 0 means that the panel passed all impact cases; similarly, an average NDI rating of 4 means the panel failed all impact cases. The average does not provide any insight into which impact conditions were failed for non-zero average NDI ratings.

The data in Table 51 was further reorganized by sorting by protective skin areal weight (protective skin psf) as shown in Table 52. Examining the areal weights illustrates the process variation in manufacturing the protective skins. In some cases (e.g., IM-90 and IM-92 with 3 mm Soric LRC) the protective skins weigh exactly the same whether they have the Tegris LM or Innegra impact spreading layer. In other cases (e.g., IM-94 and IM-95) the protective skin weight varies from 0.296 psf to 0.328 psf for Innegra and Tegris LM, respectively. The variation is due to difficulty in fully wetting the Soric and in fully wetting the Tegris. The resin application process was done by hand using a brush.

The lowest areal weight is the base substrate panel (IM-01) with a protective skin psf of 0 since there is no protective skin. Next lightest is panel IM-100 (the Polydamp hydrophobic melamine with metalized PEEK skin) with a protective skin areal weight of 0.229 psf. The Polydamp material is ¾" thick with most of the thickness being the melamine material which is a very low density and fragile foam. The Polydamp material does not impress as suitable for an external aircraft application.

The required areal weight range for the protective skin impact absorbing and impact spreading layers was 0.09 – 0.40 psf from the metrics development work. Only 12 of the impact panels have protective skin areal weights less than 0.4 psf; extending the range to 0.5 psf adds another 10 panels.

Table 52 shows that many of the lighter impact test panels do not pass all test conditions (seen with NDI values great than "2" in the table). All of the panels which did pass all of the impact conditions are shown in Table 53**.** The lightest panel that meets all of the requirements is IM-16 which is made of 20 lb polyurethane core with a carbon epoxy spreading layer; it has a protective skin areal weight of 0.730 psf (significantly greater than the desired upper limit of 0.5 psf). Most of the weights are above 1.0 and many are above 2.0 psf.

Table 51 - Reformatted Impact Data (1 of 2)

				.5" Impacter			1.0" Impacter			1.75" Impacter			
Panel ID	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	Avg. NDI
IM-01	None	None	0.000	3	4	4	2	4	4	2	4	4	3.444
IM-02	10# PU core, 1/4" T	Carbon epoxy	0.536	0	4	4	0	0	0	0	0	0	0.889
IM-03	10# PU core, 1/4" T	Innegra	0.475	0	3	4	0	0	0	0	0	0	0.778
IM-04	10# PU core, 1/4" T	0.012" alum	0.634	0	0	4	0	0	0	0	0	0	0.444
IM-05	10# PU core, 1/4" T	Tegris LM	0.473	0	4	4	0	0	0	0	0	0	0.889
IM-06	10# PU core, 1/2" T	Carbon epoxy	0.770	0	0	4	0	0	0	0	0	0	0.444
IM-07	10# PU core, 1/2" T	Innegra	0.695	0	0	4	0	0	0	0	0	0	0.444
IM-08	10# PU core, 1/2" T	Tegris LM	0.684	0	0	4	0	0	0	0	0	0	0.444
IM-09	10# PU core, 3/4" T	Carbon epoxy	0.948	0	0	0	0	0	0	0	0	0	0.000
IM-10	10# PU core, 3/4" T	Innegra	0.890	0	0	0	0	0	0	0	0	0	0.000
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	0	0	0	0	0	0	0	0	0	0.000
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	0	0	0	0	0	0	0	0	0	0.000
IM-13	10# PU core, 1" T	Innegra	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-14	10# PU core, 1" T	0.012" alum	1.233	0	0	0	0	0	0	0	0	0	0.000
IM-15	10# PU core, 1" T	Tegris LM	1.095	0	0	0	0	0	0	0	0	0	0.000
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	0	0	0	0	0	0	0	0	0	0.000
IM-17	20# PU core, 1/4" T	Innegra	0.670	0	0	3	0	0	0	0	0	0	0.333
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	0	0	0	0	0	0	0	0	0	0.000
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	0	0	3	0	0	0	0	0	0	0.333
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	0	0	0	0	0	0	0	0	0	0.000
IM-21	20# PU core, 1/2" T	Innegra	1.065	0	0	0	0	0	0	0	0	0	0.000
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	0	0	0	0	0	0	0	0	0	0.000
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	0	0	0	0	0	0	0	0	0	0.000
IM-24	20# PU core, 3/4" T	Innegra	1.458	0	0	0	0	0	0	0	0	0	0.000
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	0	0	0	0	0	0	0	0	0	0.000
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	0	0	0	0	0	0	0	0	0	0.000
IM-27	20# PU core, 1" T	Innegra	1.833	0	0	0	0	0	0	0	0	0	0.000
IM-28	20# PU core, 1" T	0.012" alum	2.005	0	0	0	0	0	0	0	0	0	0.000
IM-29	20# PU core, 1" T	Tegris LM	1.928	0	0	0	0	0	0	0	0	0	0.000
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	0	0	0	0	0	0	0	0	0	0.000
IM-31	30# PU core, 1/4" T	Innegra	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	0	0	0	0	0	0	0	0	0	0.000
IM-35	30# PU core, 1/2" T	Innegra	1.475	0	0	0	0	0	0	0	0	0	0.000
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	0	0	0	0	0	0	0	0	0	0.000
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	0	0	0	0	0	0	0	0	0	0.000
IM-38	30# PU core, 3/4" thick	Innegra	2.075	0	0	0	0	0	0	0	0	0	0.000
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	0	0	0	0	0	0	0	0	0	0.000
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	0	0	0	0	0	0	0	0	0	0.000
IM-41	30# PU core, 1" T	Innegra	2.658	0	0	0	0	0	0	0	0	0	0.000
IM-43	30# PU core, 1" T	Tegris LM	2.670	0	0	0	0	0	0	0	0	0	0.000
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	0	4	4	0	0	0	0	0	0	0.889
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	0	4	4	0	0	0	0	0	0	0.889
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	0	4	4	0	0	0	0	0	0	0.889
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	0	4	4	0	0	0	0	0	0	0.889
IM-48	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.565	0	4	4	0	0	0	0	0	0	0.889
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	0	4	4	0	0	0	0	0	0	0.889

Table 51 - Reformatted Impact Data (2 of 2)

				.5" Impacter			1.0" Impacter			1.75" Impacter			
Panel ID	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	Avg. NDI
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	0	4	4	0	0	0	0	0	0	0.889
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	0	4	4	0	0	0	0	0	0	0.889
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	0	4	4	0	0	0	0	0	0	0.889
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	0	4	4	0	0	0	0	0	0	0.889
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	0	3	4	0	0	0	0	0	0	0.778
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	0	0	4	0	0	0	0	0	0	0.444
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	0	1	3	0	0	0	0	0	0	0.444
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	0	4	4	0	0	0	0	0	0	0.889
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	0	4	4	0	0	0	0	0	0	0.889
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	0	2	4	0	0	3	0	0	0	1.000
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	0	2	4	0	0	0	0	0	0	0.667
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	0	4	4	0	0	0	0	0	0	0.889
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	0	4	4	0	0	0	0	0	0	0.889
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	0	4	4	0	0	0	0	0	0	0.889
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	0	4	4	0	0	0	0	0	0	0.889
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	0	0	4	0	0	0	0	0	0	0.444
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	0	4	4	0	0	0	0	0	0	0.889
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	0	4	4	0	0	0	0	0	0	0.889
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	0	2	4	0	0	0	0	0	0	0.667
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	0	0	0	0	0	0	0	0	0	0.000
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	0	0	0	0	0	0	0	0	0	0.000
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	0	0	4	0	0	0	0	0	0	0.444
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	0	4	4	0	0	0	0	0	0	0.889
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	0	4	4	0	0	0	0	0	0	0.889
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	0	1	4	0	0	0	0	0	0	0.556
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	0	4	4	0	0	0	0	0	0	0.889
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	0	4	4	0	0	0	0	0	0	0.889
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	0	2	4	0	0	0	0	0	0	0.667
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	0	4	4	0	0	0	0	0	0	0.889
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	0	2	4	0	0	0	0	0	0	0.667
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	0	2	4	0	0	0	0	0	0	0.667
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	0	4	4	0	0	0	0	0	0	0.889
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	0	0	0	0	0	0	0	0	0	0.000
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	0	0	0	0	0	0	0	0	0	0.000
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	0	0	0	0	0	0	0	0	0	0.000
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	0	3	4	0	0	4	0	0	0	1.222
IM-87	Soric LRC, 2mm T	Innegra	0.328	0	4	4	0	3	4	0	3	3	2.333
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	0	4	4	0	4	4	0	0	0	1.778
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	0	4	4	0	0	4	0	0	0	1.333
IM-90	Soric LRC, 3mm T	Innegra	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	0	4	4	0	0	0	0	0	0	0.889
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	0	4	4	0	0	4	0	0	0	1.333
IM-94	Soric XF, 2mm T	Innegra	0.296	0	4	4	0	4	4	0	0	0	1.778
IM-95	Soric XF, 2mm T	Tegris LM	0.328	0	4	4	0	3	4	0	3	4	2.444
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	0	4	4	0	0	0	0	0	0	0.889
IM-97	Soric XF, 6mm T	Innegra	0.351	0	4	4	0	3	4	0	0	0	1.667
IM-98	Soric XF, 6mm T	0.012" alum	0.469	0	3	4	0	0	0	0	0	0	0.778
IM-99	Soric XF, 6mm T	Tegris LM	0.366	0	4	4	0	1	3	0	0	0	1.333
IM-100	PHM w/PEEK (3/4" T)	None	0.229	0	4	N/A	0	0	4	0	0	0	1.333

Table 52 - Impact Data Organized with Increasing Protective Skin Areal Density (1 of 2)

Panel ID	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	.5" Impacter			1.0" Impacter			1.75" Impacter			Avg. NDI
				50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	
IM-01	None	None	0.000	3	4	4	2	4	4	2	4	4	3.444
IM-100	PHM w/PEEK (3/4" T)	None	0.229	0	4	N/A	0	0	4	0	0	0	1.333
IM-94	Soric XF, 2mm T	Innegra	0.296	0	4	4	0	4	4	0	0	0	1.778
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-90	Soric LRC, 3mm T	Innegra	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	0	4	4	0	4	4	0	0	0	1.778
IM-87	Soric LRC, 2mm T	Innegra	0.328	0	4	4	0	3	4	0	3	3	2.333
IM-95	Soric XF, 2mm T	Tegris LM	0.328	0	4	4	0	3	4	0	3	4	2.444
IM-97	Soric XF, 6mm T	Innegra	0.351	0	4	4	0	3	4	0	0	0	1.667
IM-99	Soric XF, 6mm T	Tegris LM	0.366	0	4	4	0	1	3	0	0	0	1.333
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	0	4	4	0	0	4	0	0	0	1.333
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	0	4	4	0	0	4	0	0	0	1.333
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	0	3	4	0	0	4	0	0	0	1.222
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	0	4	4	0	0	0	0	0	0	0.889
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	0	4	4	0	0	0	0	0	0	0.889
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	0	4	4	0	0	0	0	0	0	0.889
IM-98	Soric XF, 6mm T	0.012" alum	0.469	0	3	4	0	0	0	0	0	0	0.778
IM-05	10# PU core, 1/4" T	Tegris LM	0.473	0	4	4	0	0	0	0	0	0	0.889
IM-03	10# PU core, 1/4" T	Innegra	0.475	0	3	4	0	0	0	0	0	0	0.778
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	0	4	4	0	0	0	0	0	0	0.889
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	0	4	4	0	0	0	0	0	0	0.889
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	0	2	4	0	0	3	0	0	0	1.000
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	0	4	4	0	0	0	0	0	0	0.889
IM-75	9 pcf Al H/C, 1/4" T	Tegris LM	0.501	0	4	4	0	0	0	0	0	0	0.889
IM-73	9 pcf Al H/C, 1/4" T	Innegra	0.505	0	4	4	0	0	0	0	0	0	0.889
IM-91	Soric LRC, 3mm T	0.012" alum	0.520	0	4	4	0	0	0	0	0	0	0.889
IM-50	3 pcf Al H/C, 1/2" T	Tegris LM	0.531	0	4	4	0	0	0	0	0	0	0.889
IM-02	10# PU core, 1/4" T	Carbon epoxy	0.536	0	4	4	0	0	0	0	0	0	0.889
IM-58	6 pcf Al H/C, 1/4" T	Carbon epoxy	0.541	0	4	4	0	0	0	0	0	0	0.889
IM-46	3 pcf Al H/C, 1/4" T	0.012" alum	0.545	0	4	4	0	0	0	0	0	0	0.889
IM-52	3 pcf Al H/C, 3/4" T	Innegra	0.556	0	4	4	0	0	0	0	0	0	0.889
IM-48	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.565	0	4	4	0	0	0	0	0	0	0.889
IM-53	3 pcf Al H/C, 3/4" T	Tegris LM	0.578	0	4	4	0	0	0	0	0	0	0.889
IM-72	9 pcf Al H/C, 1/4" T	Carbon epoxy	0.584	0	4	4	0	0	0	0	0	0	0.889
IM-64	6 pcf Al H/C, 1/2" T	Tegris LM	0.610	0	4	4	0	0	0	0	0	0	0.889
IM-57	3 pcf Al H/C, 1" T	Tegris LM	0.611	0	4	4	0	0	0	0	0	0	0.889
IM-51	3 pcf Al H/C, 3/4" T	Carbon epoxy	0.615	0	4	4	0	0	0	0	0	0	0.889
IM-63	6 pcf Al H/C, 1/2" T	Innegra	0.620	0	4	4	0	0	0	0	0	0	0.889
IM-55	3 pcf Al H/C, 1" T	Innegra	0.621	0	0	4	0	0	0	0	0	0	0.444
IM-60	6 pcf Al H/C, 1/4" T	0.012" alum	0.628	0	2	4	0	0	0	0	0	0	0.667
IM-74	9 pcf Al H/C, 1/4" T	0.012" alum	0.629	0	1	4	0	0	0	0	0	0	0.556
IM-04	10# PU core, 1/4" T	0.012" alum	0.634	0	0	4	0	0	0	0	0	0	0.444
IM-78	9 pcf Al H/C, 1/2" T	Tegris LM	0.645	0	4	4	0	0	0	0	0	0	0.889
IM-62	6 pcf Al H/C, 1/2" T	Carbon epoxy	0.661	0	4	4	0	0	0	0	0	0	0.889
IM-77	9 pcf Al H/C, 1/2" T	Innegra	0.666	0	2	4	0	0	0	0	0	0	0.667
IM-17	20# PU core, 1/4" T	Innegra	0.670	0	0	3	0	0	0	0	0	0	0.333
IM-19	20# PU core, 1/4" T	Tegris LM	0.678	0	0	3	0	0	0	0	0	0	0.333
IM-08	10# PU core, 1/2" T	Tegris LM	0.684	0	0	4	0	0	0	0	0	0	0.444
IM-54	3 pcf Al H/C, 1" T	Carbon epoxy	0.688	0	3	4	0	0	0	0	0	0	0.778

Figure 52 - Impact Data Organized with Increasing Protective Skin Areal Density (2 of 2)

				.5" Impacter			1.0" Impacter			1.75" Impacter			
Panel ID	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	Avg. NDI
IM-07	10# PU core, 1/2" T	Innegra	0.695	0	0	4	0	0	0	0	0	0	0.444
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	0	0	0	0	0	0	0	0	0	0.000
IM-76	9 pcf Al H/C, 1/2" T	Carbon epoxy	0.735	0	4	4	0	0	0	0	0	0	0.889
IM-66	6 pcf Al H/C, 3/4" T	Innegra	0.749	0	4	4	0	0	0	0	0	0	0.889
IM-56	3 pcf Al H/C, 1" T	0.012" alum	0.769	0	1	3	0	0	0	0	0	0	0.444
IM-06	10# PU core, 1/2" T	Carbon epoxy	0.770	0	0	4	0	0	0	0	0	0	0.444
IM-67	6 pcf Al H/C, 3/4" T	Tegris LM	0.770	0	4	4	0	0	0	0	0	0	0.889
IM-80	9 pcf Al H/C, 3/4" T	Innegra	0.803	0	2	4	0	0	0	0	0	0	0.667
IM-81	9 pcf Al H/C, 3/4" T	Tegris LM	0.810	0	4	4	0	0	0	0	0	0	0.889
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	0	0	0	0	0	0	0	0	0	0.000
IM-65	6 pcf Al H/C, 3/4" T	Carbon epoxy	0.819	0	0	4	0	0	0	0	0	0	0.444
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	0	0	0	0	0	0	0	0	0	0.000
IM-31	30# PU core, 1/4" T	Innegra	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-79	9 pcf Al H/C, 3/4" T	Carbon epoxy	0.869	0	2	4	0	0	0	0	0	0	0.667
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	0	0	0	0	0	0	0	0	0	0.000
IM-10	10# PU core, 3/4" T	Innegra	0.890	0	0	0	0	0	0	0	0	0	0.000
IM-71	6 pcf Al H/C, 1" T	Tegris LM	0.904	0	0	4	0	0	0	0	0	0	0.444
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	0	0	0	0	0	0	0	0	0	0.000
IM-09	10# PU core, 3/4" T	Carbon epoxy	0.948	0	0	0	0	0	0	0	0	0	0.000
IM-68	6 pcf Al H/C, 1" T	Carbon epoxy	0.953	0	2	4	0	0	0	0	0	0	0.667
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	0	0	0	0	0	0	0	0	0	0.000
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	0	0	0	0	0	0	0	0	0	0.000
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	0	0	0	0	0	0	0	0	0	0.000
IM-21	20# PU core, 1/2" T	Innegra	1.065	0	0	0	0	0	0	0	0	0	0.000
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	0	0	0	0	0	0	0	0	0	0.000
IM-15	10# PU core, 1" T	Tegris LM	1.095	0	0	0	0	0	0	0	0	0	0.000
IM-13	10# PU core, 1" T	Innegra	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	0	0	0	0	0	0	0	0	0	0.000
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	0	0	0	0	0	0	0	0	0	0.000
IM-14	10# PU core, 1" T	0.012" alum	1.233	0	0	0	0	0	0	0	0	0	0.000
IM-24	20# PU core, 3/4" T	Innegra	1.458	0	0	0	0	0	0	0	0	0	0.000
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	0	0	0	0	0	0	0	0	0	0.000
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	0	0	0	0	0	0	0	0	0	0.000
IM-35	30# PU core, 1/2" T	Innegra	1.475	0	0	0	0	0	0	0	0	0	0.000
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	0	0	0	0	0	0	0	0	0	0.000
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	0	0	0	0	0	0	0	0	0	0.000
IM-27	20# PU core, 1" T	Innegra	1.833	0	0	0	0	0	0	0	0	0	0.000
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	0	0	0	0	0	0	0	0	0	0.000
IM-29	20# PU core, 1" T	Tegris LM	1.928	0	0	0	0	0	0	0	0	0	0.000
IM-28	20# PU core, 1" T	0.012" alum	2.005	0	0	0	0	0	0	0	0	0	0.000
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	0	0	0	0	0	0	0	0	0	0.000
IM-38	30# PU core, 3/4" thick	Innegra	2.075	0	0	0	0	0	0	0	0	0	0.000
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	0	0	0	0	0	0	0	0	0	0.000
IM-41	30# PU core, 1" T	Innegra	2.658	0	0	0	0	0	0	0	0	0	0.000
IM-43	30# PU core, 1" T	Tegris LM	2.670	0	0	0	0	0	0	0	0	0	0.000
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	0	0	0	0	0	0	0	0	0	0.000

Table 53 - Panels That Passed All Test Conditions Sorted by Protective Skin Areal Density

				.5" Impacter			1.0" Impacter			1.75" Impacter			
Panel ID	Impact Absorbing Layer	Impact Spreading Layer	Protective Skin psf	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	50 in-lbs	180 in-lbs	250 in-lbs	Avg. NDI
IM-16	20# PU core, 1/4" T	Carbon epoxy	0.730	0	0	0	0	0	0	0	0	0	0.000
IM-18	20# PU core, 1/4" T	0.012" alum	0.814	0	0	0	0	0	0	0	0	0	0.000
IM-11	10# PU core, 3/4" T	Tegris LM	0.853	0	0	0	0	0	0	0	0	0	0.000
IM-31	30# PU core, 1/4" T	Innegra	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-33	30# PU core, 1/4" T	Tegris LM	0.866	0	0	0	0	0	0	0	0	0	0.000
IM-69	6 pcf Al H/C, 1" T	Innegra	0.875	0	0	0	0	0	0	0	0	0	0.000
IM-10	10# PU core, 3/4" T	Innegra	0.890	0	0	0	0	0	0	0	0	0	0.000
IM-30	30# PU core, 1/4" T	Carbon epoxy	0.928	0	0	0	0	0	0	0	0	0	0.000
IM-09	10# PU core, 3/4" T	Carbon epoxy	0.948	0	0	0	0	0	0	0	0	0	0.000
IM-83	9 pcf Al H/C, 1" T	Innegra	0.968	0	0	0	0	0	0	0	0	0	0.000
IM-85	9 pcf Al H/C, 1" T	Tegris LM	0.988	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-32	30# PU core, 1/4" T	0.012" alum	1.003	0	0	0	0	0	0	0	0	0	0.000
IM-70	6 pcf Al H/C, 1" T	0.012" alum	1.033	0	0	0	0	0	0	0	0	0	0.000
IM-82	9 pcf Al H/C, 1" T	Carbon epoxy	1.040	0	0	0	0	0	0	0	0	0	0.000
IM-21	20# PU core, 1/2" T	Innegra	1.065	0	0	0	0	0	0	0	0	0	0.000
IM-22	20# PU core, 1/2" T	Tegris LM	1.088	0	0	0	0	0	0	0	0	0	0.000
IM-15	10# PU core, 1" T	Tegris LM	1.095	0	0	0	0	0	0	0	0	0	0.000
IM-13	10# PU core, 1" T	Innegra	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-84	9 pcf Al H/C, 1" T	0.012" alum	1.100	0	0	0	0	0	0	0	0	0	0.000
IM-20	20# PU core, 1/2" T	Carbon epoxy	1.133	0	0	0	0	0	0	0	0	0	0.000
IM-12	10# PU core, 1" T	Carbon epoxy	1.163	0	0	0	0	0	0	0	0	0	0.000
IM-14	10# PU core, 1" T	0.012" alum	1.233	0	0	0	0	0	0	0	0	0	0.000
IM-24	20# PU core, 3/4" T	Innegra	1.458	0	0	0	0	0	0	0	0	0	0.000
IM-36	30# PU core, 1/2" T	Tegris LM	1.465	0	0	0	0	0	0	0	0	0	0.000
IM-25	20# PU core, 3/4" T	Tegris LM	1.470	0	0	0	0	0	0	0	0	0	0.000
IM-35	30# PU core, 1/2" T	Innegra	1.475	0	0	0	0	0	0	0	0	0	0.000
IM-23	20# PU core, 3/4" T	Carbon epoxy	1.490	0	0	0	0	0	0	0	0	0	0.000
IM-34	30# PU core, 1/2" T	Carbon epoxy	1.533	0	0	0	0	0	0	0	0	0	0.000
IM-27	20# PU core, 1" T	Innegra	1.833	0	0	0	0	0	0	0	0	0	0.000
IM-26	20# PU core, 1" T	Carbon epoxy	1.910	0	0	0	0	0	0	0	0	0	0.000
IM-29	20# PU core, 1" T	Tegris LM	1.928	0	0	0	0	0	0	0	0	0	0.000
IM-28	20# PU core, 1" T	0.012" alum	2.005	0	0	0	0	0	0	0	0	0	0.000
IM-39	30# PU core, 3/4" thick	Tegris LM	2.058	0	0	0	0	0	0	0	0	0	0.000
IM-38	30# PU core, 3/4" thick	Innegra	2.075	0	0	0	0	0	0	0	0	0	0.000
IM-37	30# PU core, 3/4" thick	Carbon epoxy	2.128	0	0	0	0	0	0	0	0	0	0.000
IM-41	30# PU core, 1" T	Innegra	2.658	0	0	0	0	0	0	0	0	0	0.000
IM-43	30# PU core, 1" T	Tegris LM	2.670	0	0	0	0	0	0	0	0	0	0.000
IM-40	30# PU core, 1" T	Carbon epoxy	2.740	0	0	0	0	0	0	0	0	0	0.000

As was mentioned in Section 7.2.1 – Impact Requirements, a realistic pass condition for the panels is to pass the 0.5" impactor at 50 in-lbs, the 1.0" impactor at 50 and 180 in-lbs, and to pass the 1.75" impactor at all energy levels. Table 54 shows only those impact conditions in the columns under each impactor diameter. Panels are sorted by areal weight, and only panels with areal weights less than 0.5 psf are shown. There are 16 panels which pass the realistic requirements; only six fail. Unfortunately, those six are some of the lightest protective skins. After IM-100, IM-92 and IM-90 at 0.31 psf are the next two panels to meet the requirements. They both use the Soric LRC (Low Resin Content) 3 mm impact absorbing layer with Tegris LM and Innegra S, respectively, for the impact spreading layer.

Table 54 - Panels with Protective Skin Areal Density Less Than 0.50 psf

					.5" Impacter	1.0" Impacter		1.75" Impacter		
Panel	Absorbing Layer	Absorb T	Spreading Layer	psf	50	50	180	50	180	250
IM-1	None	0.000	None	0.000	3	2	4	2	4	4
IM-100	PHM w/PEEK	0.750	None	0.229	0	0	0	0	0	0
IM-94	Soric XF	0.079	Innegra	0.296	0	0	4	0	0	0
IM-92	Soric LRC	0.118	Tegris LM	0.310	0	0	0	0	0	0
IM-90	Soric LRC	0.118	Innegra	0.310	0	0	0	0	0	0
IM-88	Soric LRC	0.079	Tegris LM	0.311	0	0	4	0	0	0
IM-87	Soric LRC	0.079	Innegra	0.328	0	0	3	0	3	3
IM-95	Soric XF	0.079	Tegris LM	0.328	0	0	3	0	3	4
IM-97	Soric XF	0.236	Innegra	0.351	0	0	3	0	0	0
IM-99	Soric XF	0.236	Tegris LM	0.366	0	0	1	0	0	0
IM-93	Soric XF	0.079	Carbon epoxy	0.373	0	0	0	0	0	0
IM-89	Soric LRC	0.118	Carbon epoxy	0.391	0	0	0	0	0	0
IM-86	Soric LRC	0.079	Carbon epoxy	0.395	0	0	0	0	0	0
IM-47	3 pcf Al H/C	0.250	Tegris LM	0.409	0	0	0	0	0	0
IM-45	3 pcf Al H/C	0.250	Innegra	0.411	0	0	0	0	0	0
IM-96	Soric XF	0.236	Carbon epoxy	0.423	0	0	0	0	0	0
IM-98	Soric XF	0.236	0.012" alum	0.469	0	0	0	0	0	0
IM-5	10# PU core	0.250	Tegris LM	0.473	0	0	0	0	0	0
IM-3	10# PU core	0.250	Innegra	0.475	0	0	0	0	0	0
IM-61	6 pcf Al H/C	0.250	Tegris LM	0.475	0	0	0	0	0	0
IM-44	3 pcf Al H/C	0.250	Carbon epoxy	0.488	0	0	0	0	0	0
IM-59	6 pcf Al H/C	0.250	Innegra	0.490	0	0	0	0	0	0
IM-49	3 pcf Al H/C	0.500	Innegra	0.490	0	0	0	0	0	0

KEY

Failed 1.0" at 180 in-lbs

Failed 1.0" at 180 in-lbs and damage was not visible

Examining the raw data in Table 50 (the visible damage and base panel damage columns) for those panels which failed shows that the panels highlighted in mauve in Table 54 never had base panel damage with no visible damage. The panels highlighted in red did have a case or cases of base panel damage with no visible damage – in addition to not meeting the impact requirements, these panels also fail the visible damage requirement. Examination of the remainder of the panels shows that no other panels fail to meet the visible damage requirement.

The value of carbon epoxy as an impact spreading layer is evident from examining Table 54**.** Both the Soric XF and LRC 2 mm impact absorbing layer failed with Innegra and Tegris LM (with one exception), but both passed with carbon epoxy as the impact spreading layer. The carbon epoxy layer is heavier but could possibly be worth the weight in order to reduce the thickness of the impact absorbing layer. A decision to use carbon epoxy cannot be made based on impact alone, however, because the lightning strike protection due to corrosion issues would have to be copper or brass in order to be compatible – both of those options would be heavier than available aluminum options.

The 16 panels remaining in Table 54 which passed all of the realistic test conditions are all potential candidates for the next phase of protective skin development. They are called out in

Table 55. The Soric LRC 3 mm is still in play with both Tegris LM and Innegra. Soric XF 6mm is only an option with carbon epoxy or aluminum (which was included in the test matrix to compare impacts). Eliminating the panels with carbon epoxy and aluminum leaves 10 potential candidates. There are several ¼" thick 3 pcf metallic honeycomb and 10 lb polyurethane core options with both Tegris and Innegra. There are even some ¼" thick 6 pcf metallic honeycomb options and one ½" thick 3 pcf metallic honeycomb options with areal weights less than 0.5 psf.

A **major finding** from this testing was that thicker materials are not required. The test matrix included ¼", ½", ¾", and 1" thicknesses of the metallic honeycombs and polyurethane cores. Being able to use thinner skins which fulfill the requirements is excellent news from a drag perspective. The other surprise is that heavier honeycomb and core densities are not required. While two panels with 6 pcf metallic honeycomb appear in the final panel possibilities, the 3 pcf metallic honeycomb panels are also there and have a lower areal weight (0.490 psf compared to 0.411 psf with Innegra).

As mentioned in Section 7.2.2 – Attaching the Protective Skins to Base Panels, the base panels were observed to split in the direction of the top and bottom plies of the uni-directional material (see Figure 61). This necessitated ensuring the base panels were oriented with the top and bottom plies running across the test bays instead of in the long direction of the bays. The uni-directional material was chosen because representative of what might be primary structure in 2035 – it is strong and production could be automated. Year 2012 structures, which often have to deal with impact damage, replace the most outer and inner uni-directional plies with woven materials. The woven material cross fibers act like a stop to minimize crack growth (see Figure 62).

In order to obtain the best impact data possible during the next phase of testing, the base substrate panels will be constructed with five layers of uni-directional fibers between two outer layers of woven material. This should eliminate the need to worry about orientation of the base substrate panel in the test fixture and produce more accurate and accurately measureable results.

Table 55 - Final Impact Panel Possibilities

Panel ID	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	psf
IM-100	Polydamp Hydrophobic Melamine with PEEK skin (3/4" thick)	None	None	0.229
IM-92	Soric LRC, 3mm thick	Aeropoxy	Tegris LM	0.310
IM-90	Soric LRC, 3mm thick	Aeropoxy	Innegra	0.310
IM-99	SORIC XF, 6 mm thick	Aeropoxy	Tegris LM	0.366
IM-93	Soric XF, 2mm thick	Aeropoxy	Carbon epoxy	0.373
IM-89	Soric LRC, 3mm thick	Aeropoxy	Carbon epoxy	0.391
IM-86	Soric LRC, 2mm thick	Aeropoxy	Carbon epoxy	0.395
IM-47	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Tegris LM	0.409
IM-45	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra	0.411
IM-96	Soric XF, 6mm thick	Aeropoxy	Carbon epoxy	0.423
IM-98	Soric XF, 6mm thick	Aeropoxy	0.012" aluminum sheet	0.469
IM-5	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Tegris LM	0.473
IM-3	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Innegra	0.475
IM-61	6 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Tegris LM	0.475
IM-44	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Carbon epoxy	0.488
IM-49	3 pcf metallic honeycomb, 1/2" thick	Grade 30 adhesive	Innegra	0.490
IM-59	6 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra	0.490

Figure 61: Unidirectional fiber splitting after impact.

Figure 62: Woven outer layers stop splitting and crack growth.

7.3 Electromagnetic Effects

With the requirements from 5.3.1, three sets of testing were done with the lighting strike panels: 1) shielding effectiveness (HIRF or High Intensity Radiated Fields); 2) indirect effects of lightning (IEL); and 3) direct effects of lightning (DEL). (Visual inspection of the lightning strike panels was also conducted before DEL testing – that will be reported on in the next section on Aesthetics and Smoothing.) Shielding effectiveness and indirect effects of lightning testing were conducted at Cessna Aircraft Company; the direct effects' testing was conducted at DNB Engineering in Fullerton, California. The electromagnetic effects test results are shown in detail in Appendix F – First-Generation Shielding Effectiveness Test Data, Appendix G – First-Generation Indirect Effects Test Data, Appendix H – First-Generation Direct Effects (DNB) Report, and Appendix I – First-Generation Direct Effects Pictures (Cessna). Results will be summarized in the following subsections.

7.3.1 Transmissivity

A schematic of the test setup for transmissivity testing is shown in Figure 63**.** The aperture is where the panel is placed. Figure 64 through Figure 68 shows pictures of the transmissivity testing setup. More

detailed pictures along with pictures of all of the test articles mounted in the chamber may be found in Appendix E – First-Generation Shielding Effectiveness Test Setup Pictures.

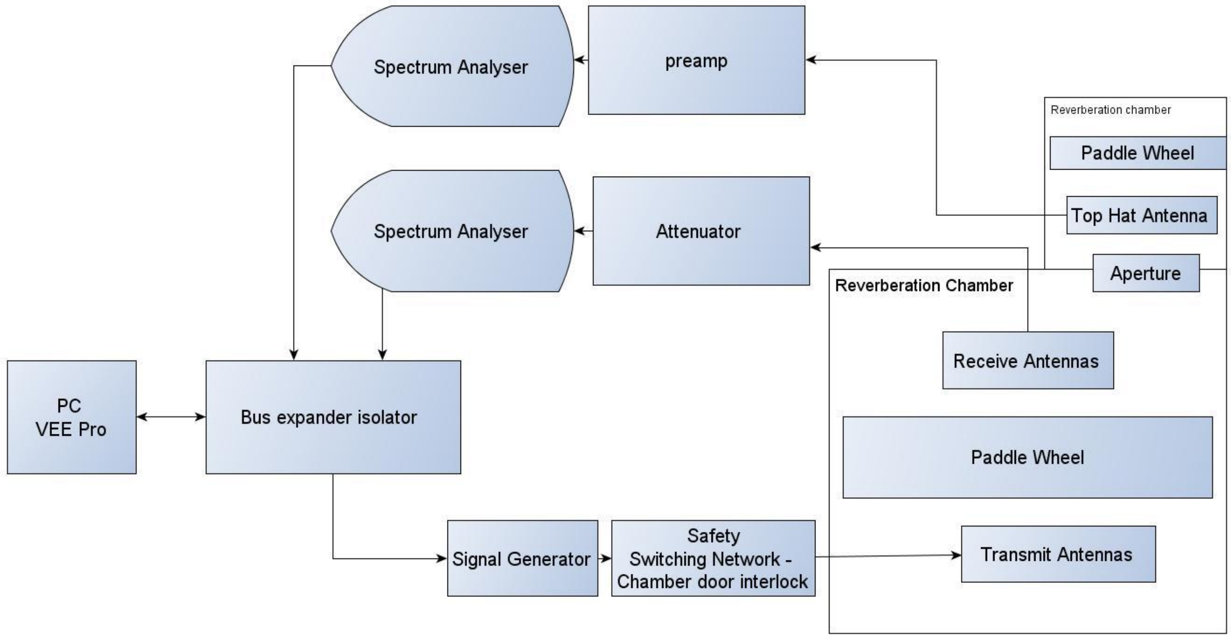


Figure 63: Schematic of shielding effectiveness setup.

Figure 64: Horn antenna in the big chamber.

Figure 65: Close-up view of horn antenna in big chamber.

Figure 66: Horn antenna in the small chamber.

Figure 67: Horn antenna in the small chamber.

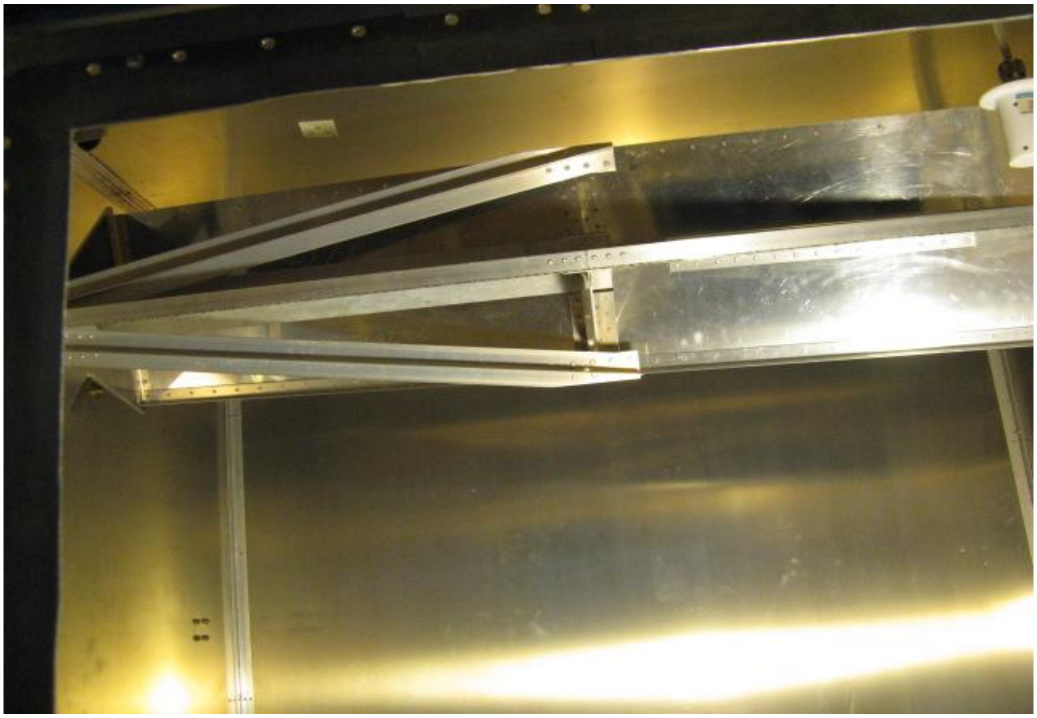


Figure 68: Mode stirrer in the small chamber.

The aperture opening is 22” x 22” so the lightning strike test panels were designed to have 22” x 22” impact absorbing and spreading layers along with lightning strike materials (see Figure 69). The outer one inch of the base substrate panel was bare; in preparation for testing, copper tape with conducting adhesive ¾” wide was applied to the edge of the protective skin and 2” tape was wrapped around the bare base substrate panel as shown in Figure 70. One key to transmissivity testing is a good ground between the edge of the panel and the window of the test chamber aperture. The edges of the test articles were designed to leave the lightning strike protection material uncovered by the aesthetic film by leaving the outer 0.75” edge of the lightning strike material bare as shown in Figure 69.

Figure 69: Lightning strike panel edge treatment to facilitate grounding.

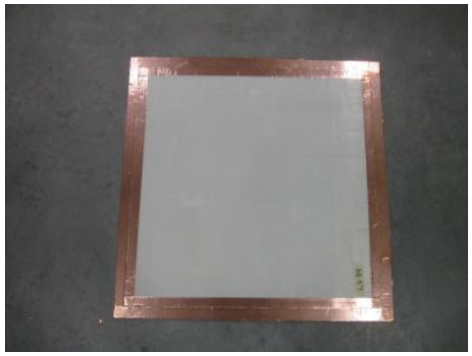


Figure 70: Test panel with copper tape to facilitate grounding.

In order to ground the test articles to the chamber wall, an innovative “L” frame as shown in the left side of Figure 71 was designed and fabricated at Cessna. The inner piece of the “L” frame has an inner edge which comes into contact with the test panel; the outer piece of the “L” frame has an outer edge which comes into contact with the chamber wall. The “L” frame is innovative in that it can be adjusted to accommodate all of the thicknesses of the test articles.

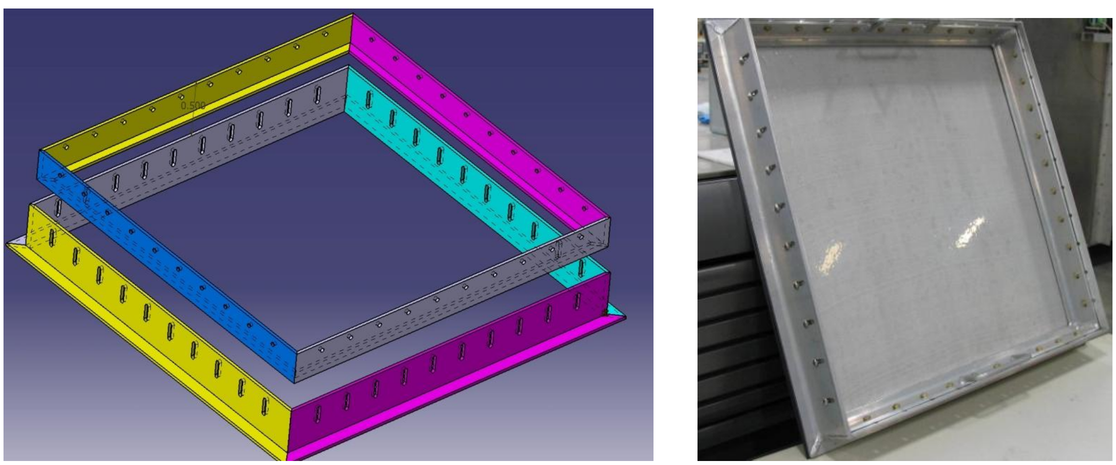


Figure 71: "L" frame drawing and article with test panel ready for testing.

Figure 72 shows a 10dB difference in the raw data of power received by the top hat antenna inside the shielded reverberation chamber for the lightning strike panel LS-4 with and without the grounding of the lightning strike material on the core to the Al frame. LS-4 used resin to attach the lightning strike material. The resin prevented grounding and caused a decrease in shielding effectiveness. In order to achieve grounding it was necessary to lightly sand the resin around the outer ¾” of the panels. The grounded result in Figure 72 shows that the sanding was effective. This also provides a validation of the “sealing” method used for the leakage current.

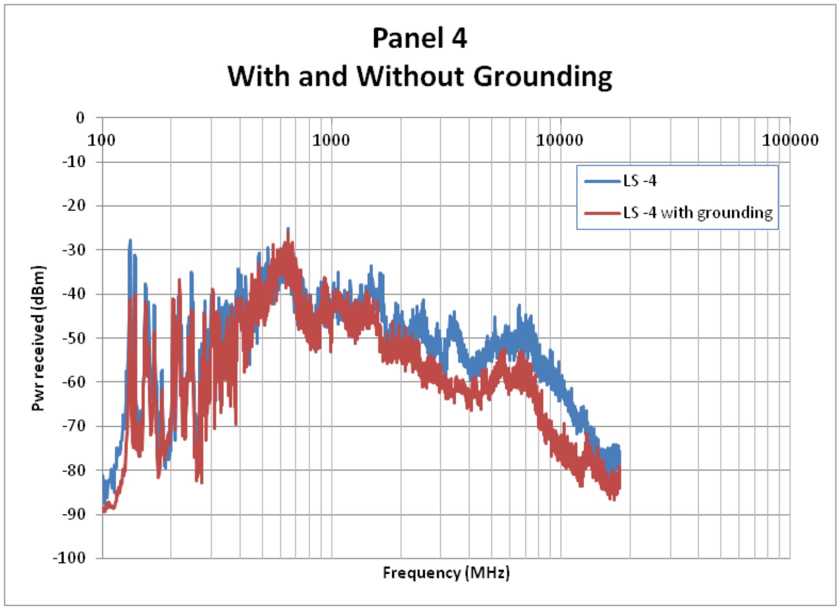


Figure 72: Panel LS-4 (10 pcf PU core, 1/4" thick VATRM Innegra VARTM LDS 50-01 0.007 psf aluminum Integument film) with and without grounding to Al frame.

Figure 73 shows the comparison between the open window, the Al panel, and the base substrate panel. There is a difference of 25 dB from 700 MHz to 6 GHz (the frequency range of interest) between the Al and base substrate panel. Addition of the protective skins is necessary to produce shielding effectiveness results closer to aluminum. Shielding effectiveness testing of the panels gives an insight into materials to be chosen to get close to the shielding effectiveness of aluminum.

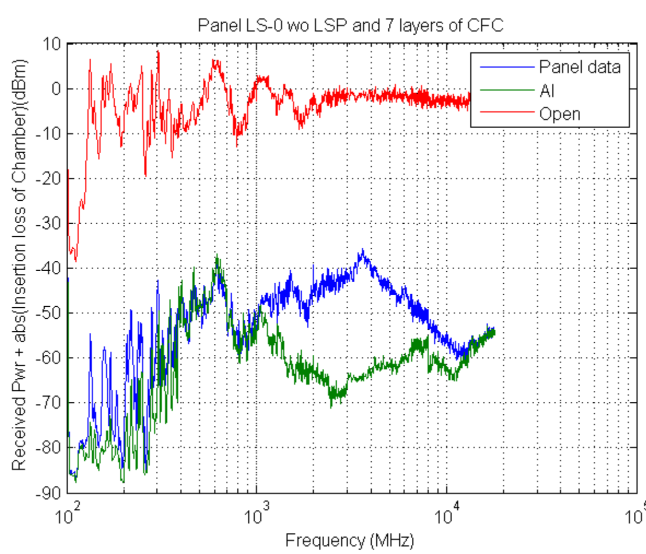


Figure 73: Shielding effectiveness of a base substrate panel compared to an Al panel and open window.

The effects of different lightning strike materials are shown in Figure 74. All of the panels have ¼" thick 10 pcf polyurethane core with an Innegra S impact spreading layer and Integument film. The

differences shown are within the noise level of the data. The shielding level is much closer to that of aluminum than the open hole.

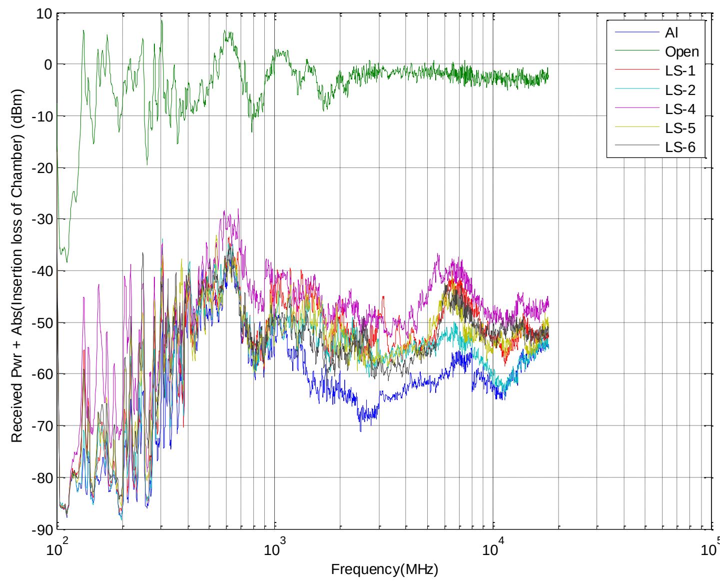


Figure 74: Different lightning strike materials with 1/4" 10 pcf PU core with Innegra S impact spreading and Integument film (LS-1 - 0.016 psf expanded Al, LS-2 - 0.029 psf expanded Copper foil, LS-4 - LDS 50-01 0.007 psf Al, LS-5 - Integument with integrated LSP and PSA, LS-6 – Proprietary Spray material).

The effect of varying impact absorbing material is shown in Figure 75. All of the materials are ¼" thick and have Innegra S impact absorbing layer and Integument film with integrated lightning strike protection (LSP) and pressure sensitive adhesive (PSA). There are no significant differences in shielding for any of the impact absorbing materials. Again the shielding levels are close to that of aluminum.

Figure 76 shows the difference in shielding for two different thicknesses of 10 pcf polyurethane core material. Both panels have Innegra S impact spreading layer, LDS 50-01 LSP, and Integument film. There is a noticeable difference in shielding levels with the ¾" thick providing more shielding than the ¼"-thick core. This is as expected since the shielding is primarily a function of material thickness. The ¾" core does provide shielding close to the same level as aluminum.

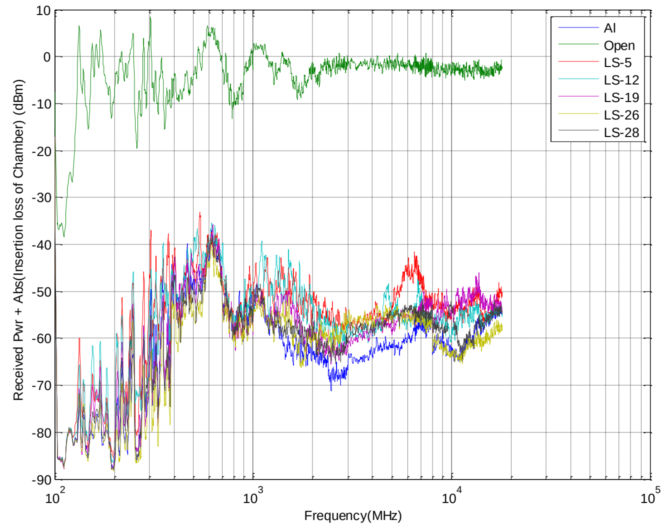


Figure 75: Different 1/4" thick impact absorbing materials with Innegra S and Integument with integrated LSP & PSA (LS-5 – 10 pcf PU core, LS-12 – 20 pcf PU core, LS-19 – 3 pcf metallic honeycomb, LS-26 – 6 pcf metallic honeycomb core; and LS-28 – 7.9 pcf metallic honeycomb core).

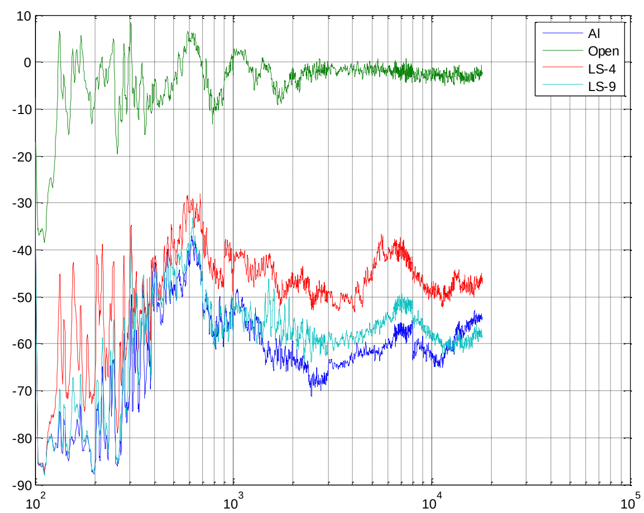


Figure 76: Comparison of two different thicknesses of polyurethane core with same lightning strike protection scheme (LS-4 1/4" and LS-9 - 3/4").

Figure 77 shows the effect of Soric thickness on shielding. No lighting strike panels were built with 3 mm Soric LRC. As would be anticipated because of the extremely small differences in thickness, there is no quantifiable difference in shielding for the various thicknesses.

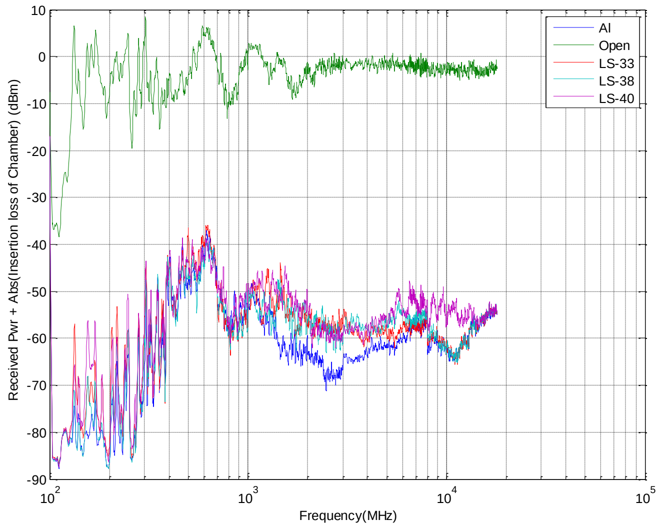


Figure 77: Soric cores of various thicknesses (LS-33 - Soric XF 2 mm, LS-38 - Soric XF 6 mm, LS-40 - Soric LRC 2 mm).

The effect of aesthetic films on shielding is shown in Figure 78. All of the panels have ¼" thick 10 pcf polyurethane core for impact absorbing, Innegra S for the impact spreading layer, and LDS 50-01 for the lightning strike layer. There appears to be a potentially significant difference between LS-4 (Integument film) and LS-41 (3M-5004) which is surprising since they have the same chemical composition. The Integument film is twice as thick (4 mils as opposed to 2 mils for the 3M 5004). For the rest of the materials, there does not appear to be any significant difference.

To investigate, a comparison of panels with Innegra S, LDS 50-01 LSP, and Integument film is shown in Figure 79. All of the panels have different impact absorbing layers; all layers are ¼" thick. LS-41 (same as LS-4 except for 3M 5004 film instead of Integument) is shown for comparison. LS-4 and LS-18 (3 pcf metallic honeycomb instead of 10 pcf PU core) have almost identical shielding results. There were no significant differences shown for various impact absorbing layers in Figure 75. The most likely explanation is that the grounding for LS-4 and LS-18 was not good (the grounding issue with LS-4 was shown earlier in Figure 72), and the most likely conclusion for aesthetic films is that there is no real effect on shielding by varying aesthetic films.

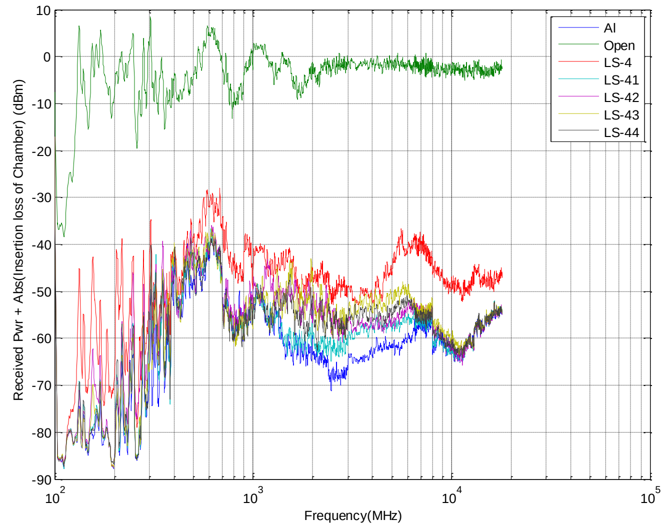


Figure 78: Different aesthetic films with same polyurethane core (LS-4 - Integument, LS-41 – 3M 5004, LS-42 – Aptiv PEEK, LS-43 – Halar ECTFE, LS-44 – Kapton film).

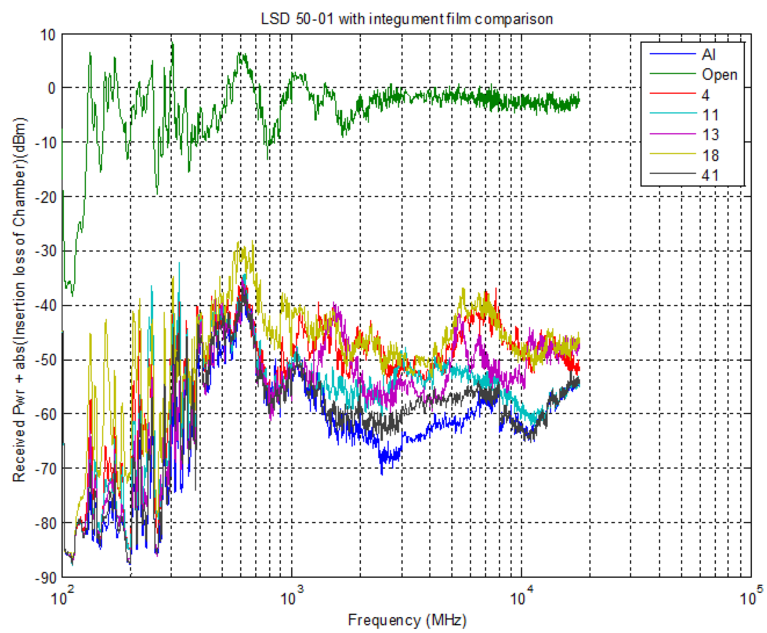


Figure 79: Panels with Innegra, LDS 50-01 LSP and Integument film (LS-4 – 10 pcf PU core, LS-11 – 20 pcf PU core, LS-13 – 30 pcf PU core, LS-18 – 3 pcf metallic honeycomb, LS-41 – 10 pcf PU core with 3M 5004 with PSA film instead of Integument).

The shielding effectiveness of the two carbon nanotube panels is presented in Figure 80. Both panels have ¼" thick 10 pcf polyurethane core, Innegra S impact spreading layer, and Integument film aesthetic layer. The difference in thicknesses of the carbon nanotube sheets is 9-11 gsm (one and then 1 ½ layers

on LS-46) and one layer of 15-18 gsm on LS-47. There is no perceptible difference between the two panels.

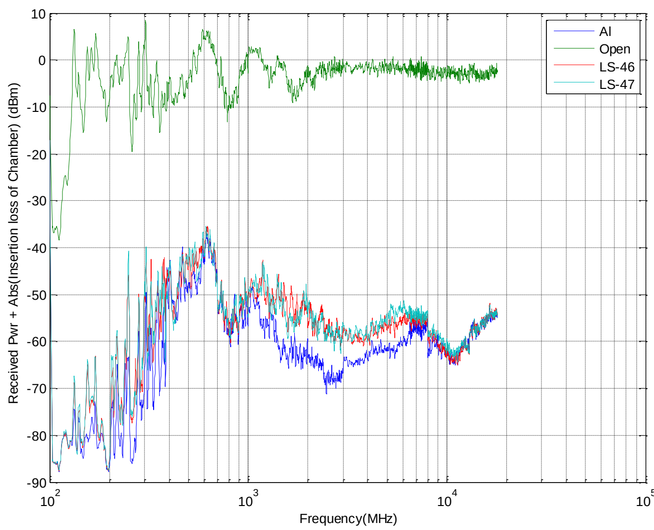


Figure 80: Panels with carbon nanotube lightning strike protection (two different densities).

The shielding effectiveness for Polydamp hydrophobic melamine with metalized PEEK skin is shown in Figure 81. The panel has no film and no other layers of materials except the base substrate panel. The Polydamp does an excellent job of shielding, coming very close to that of the aluminum panel and significantly beating the plain base substrate panel which was shown in Figure 73**.**

The shielding effectiveness for all panels (including the base panel) is overlaid on Figure 82. None of the panels are more effective than aluminum. In the outer areas of the region of interest (700 MHz to 1 GHz and 4 GHz to 6 GHz) the base panel is in the middle of the coverage areas of all panels. In the region 1 GHz to 4 GHz, all of the test panels provide more shielding than the base panel.

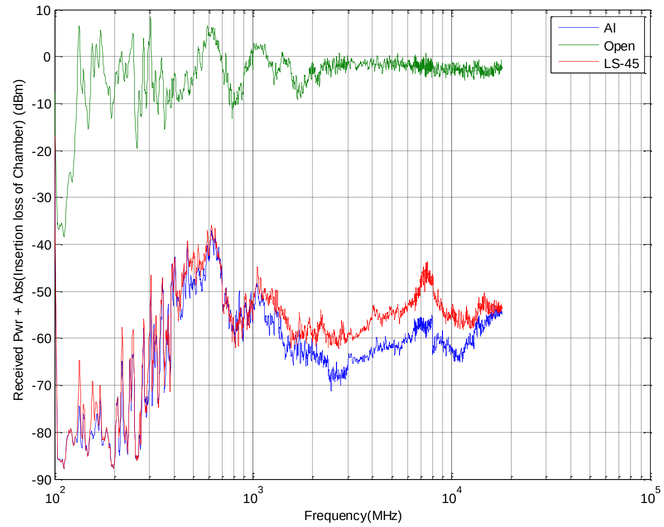


Figure 81: Effect of Polydamp hydrophobic melamine (3/4" thick) with PEEK skin - no film.

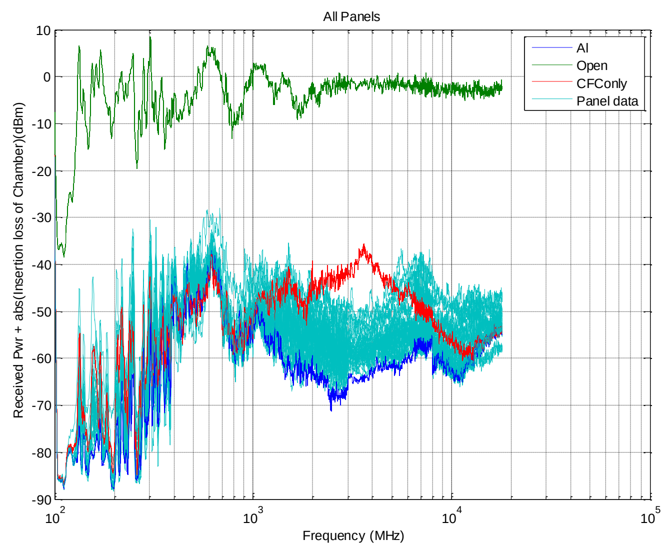


Figure 82: Shielding effectiveness for all panels plus the base panel
with aluminum and open as the two bounds.

7.3.2 Indirect Effects of Lightning

The panels were evaluated for possible effects of indirect effects of lightning coupling factors into a known "standard" wire bundle, based on Section 22 of RTCA DO-160G for open circuit voltage (Voc) and closed circuit current (Isc) for a standard cable bundle using waveforms 1 and 2.

The overall test setup for IEL testing is shown in Figure 83 through Figure 88. Figure 83 shows the complete setup with labels on the various components. Figure 84 through Figure 88 show more detailed views of each of the areas.

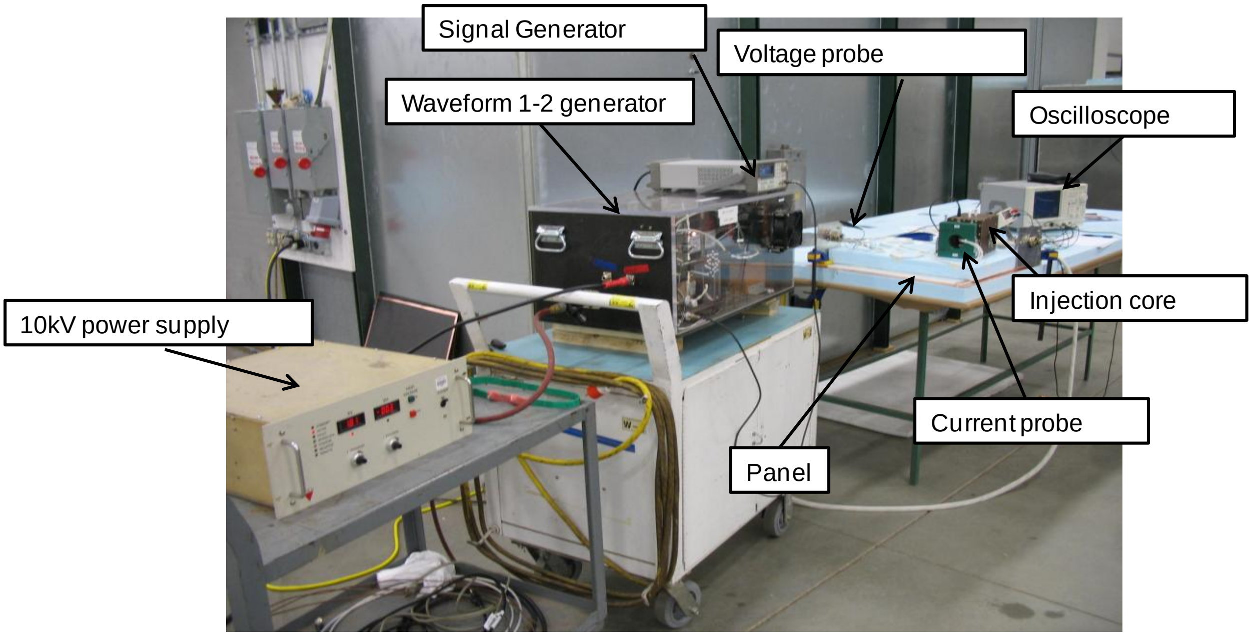


Figure 83: Complete IEL setup (test panel is between blue foam layers at far right of picture).

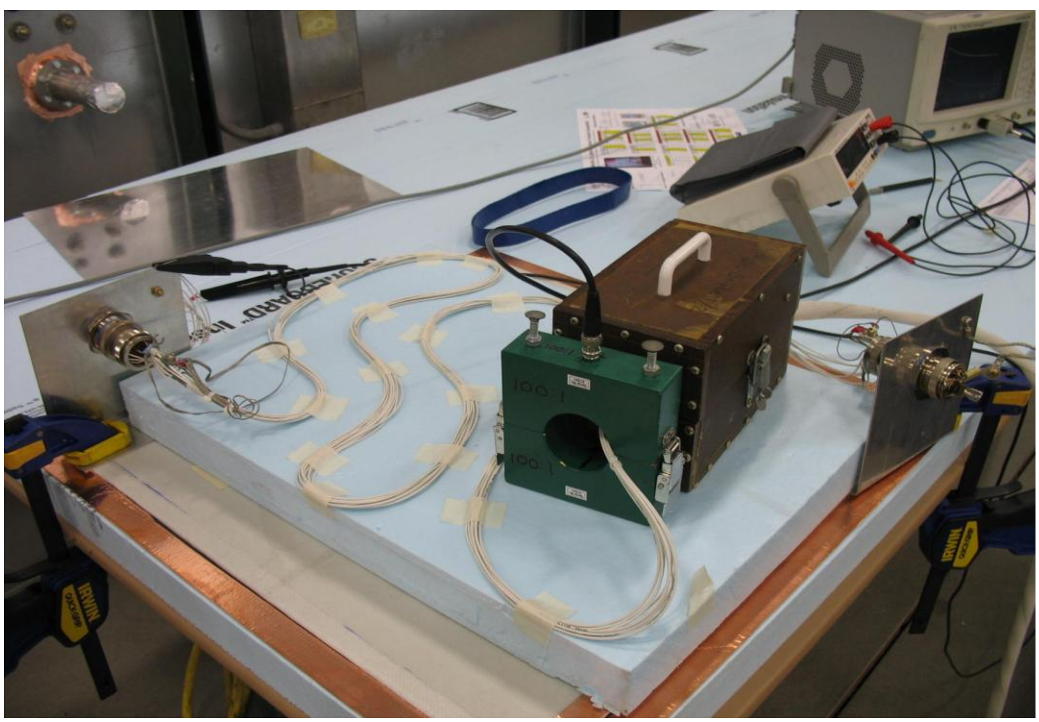


Figure 84: IEL setup - transformer with probe.

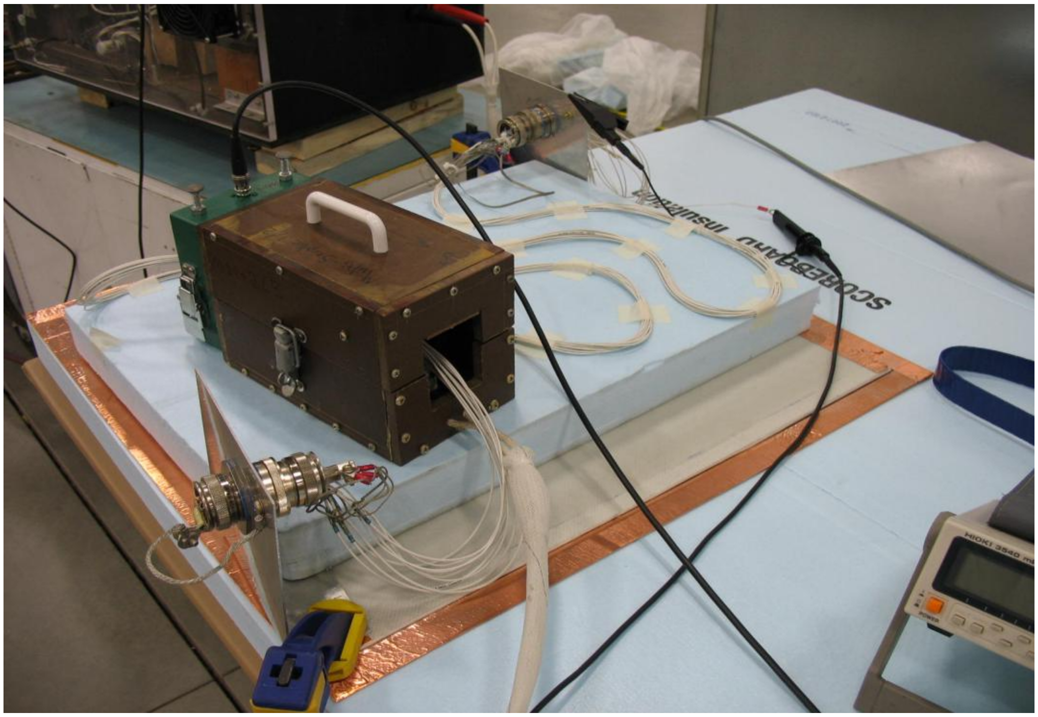


Figure 85: IEL setup - transformer with cable bundle termination.

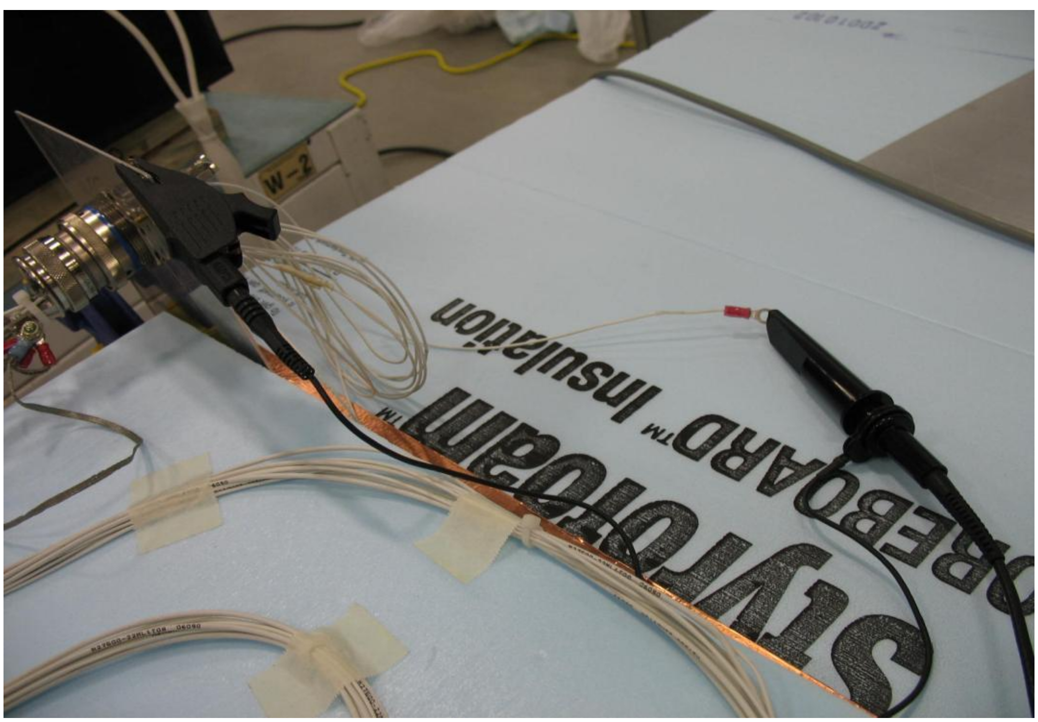


Figure 86: IEL setup - termination.

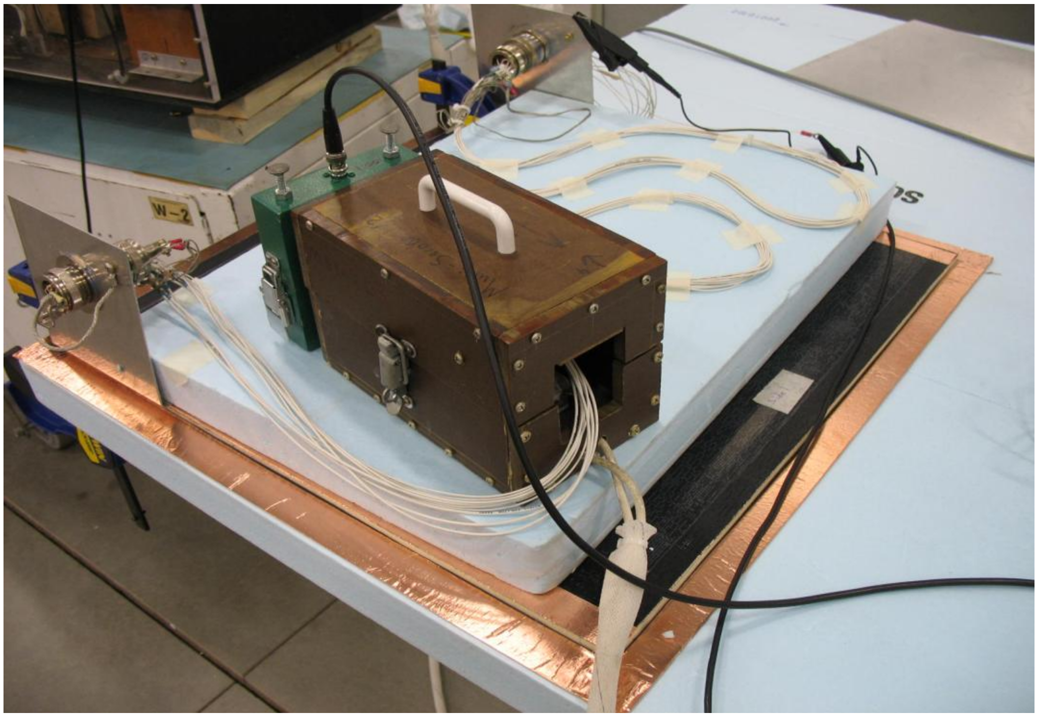


Figure 87: IEL setup - panel, cable bundle, and transformer.

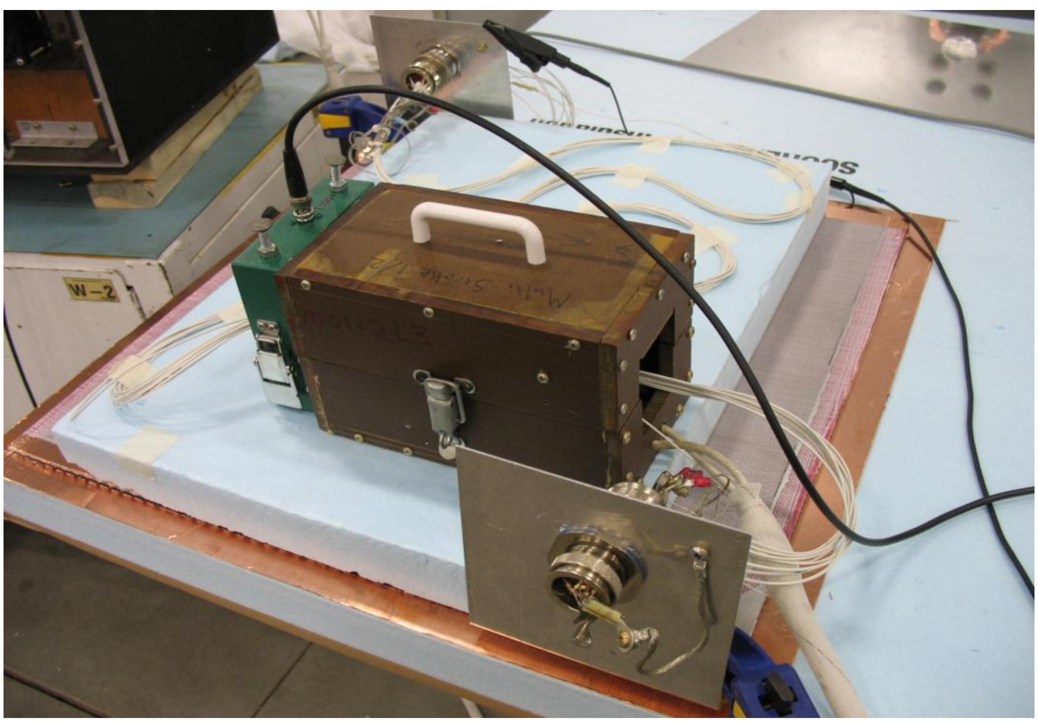


Figure 88: IEL setup - panel with bulkheads.

Current waveform 1 and voltage waveform 2 were injected on the cable bundles using an induction current transformer. All the waveforms were tested to current level 3 with a peak equal to 608 A (Figure 89), and with the impedance of the panels the voltage (Figure 90) was tested to 1.1kV - 1.2kV.

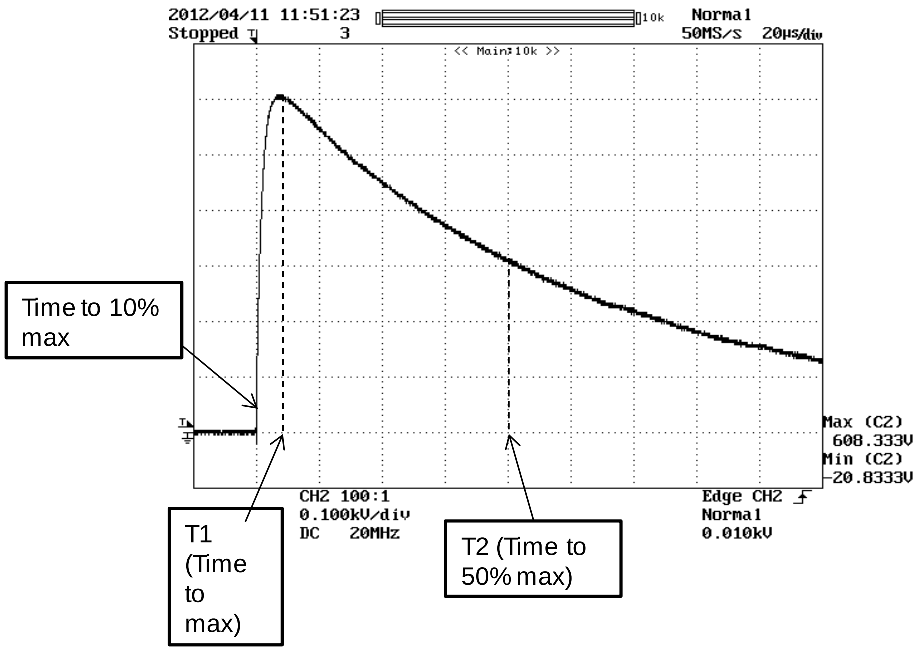


Figure 89: IEL input current waveforms with characteristics of interest identified.

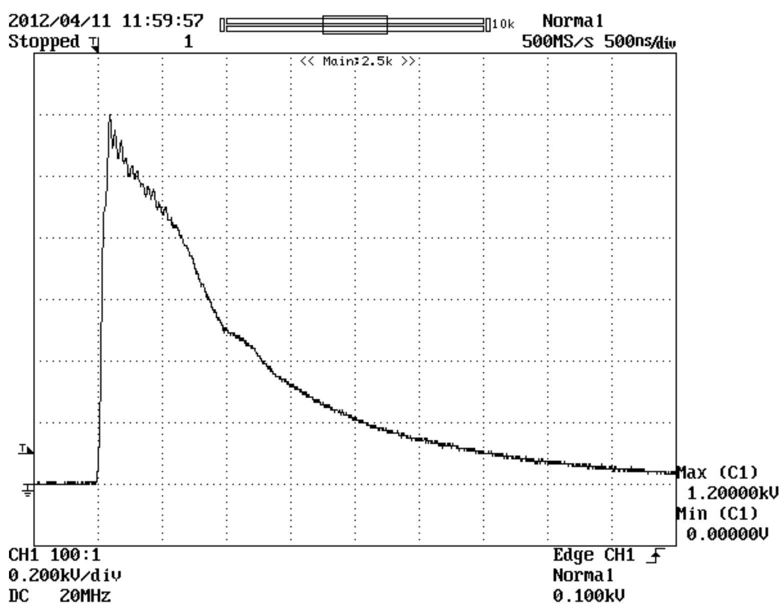


Figure 90: IEL voltage waveform.

Table 56 shows results for different lightning strike protection materials for maximum peak current, maximum peak voltage and resistance between the bulkheads. These measurements were used to attempt to make a relative comparison of the important waveform parameters between the various materials. Table 57 shows some of the panels as compared to Al panel (433A, 0.97mΩ). These panels chosen were a representative of the lightning strike protection material. Table 58 for current and Table 59 for voltage were obtained by digitizing measured signals of closed circuit current and open circuit voltage on the cable bundle. Peak voltage varied from 16V – 19V for all materials except for three outliers (carbon nanotube and the Polydamp Hydrophobic Melamine with metalized PEEK skin), and peak current varied from 433A - 362A for all of the materials except for three outliers (carbon nanotube and the Polydamp Hydrophobic Melamine with metalized PEEK skin).

Table 56 - Panel Details with Peak Current and Voltage (1 of 2)

Panel ID	Lightning Strike Material	Current (A)	Voltage (V)	Resistance (m Ω)
Al	Al	433	18	0.97
CFC	None	358	15	41.4
LS-01	0.016 psf expanded aluminum foil	424.5	18	5.9
LS-02	0.029 expanded copper foil	424.5	17.5	8.6
LS-04	LDS 50-01 0.007 psf aluminum	416	17	17.1
LS-05	Integument with integrated LSP	425	18	12.8
LS-06	Proprietary Spray Material	370.5	15.5	20.2
LS-07	Integument with integrated LSP	425	18	7.9
LS-08	Integument with integrated LSP	420.5	18	11.2
LS-09	LDS 50-01 0.007 psf aluminum	408	16.5	18.5
LS-10	Integument with integrated LSP	429	18	6.9
LS-11	LDS 50-01 0.007 psf aluminum	420.5	18	21.1
LS-12	Integument with integrated LSP	425	18.5	7.7
LS-13	LDS 50-01 0.007 psf aluminum	425	17.5	9.8
LS-14	Integument with integrated LSP	420.5	18	7.9
LS-15	0.016 psf expanded aluminum foil	429	18	35.6
LS-16	0.029 expanded copper foil	429	17	8.3
LS-18	LDS 50-01 0.007 psf aluminum	425	18	22.6
LS-19	Integument with integrated LSP	425	17	8.1
LS-20	Proprietary Spray Material	370.5	15.5	37.5
LS-21	Integument with integrated LSP	424.5	17.5	6.4
LS-22	Integument with integrated LSP	425	19	15
LS-23	LDS 50-01 0.007 psf aluminum	416.5	17	13.5
LS-24	Integument with integrated LSP	424.5	18	8.4
LS-25	LDS 50-01 0.007 psf aluminum	416	17.5	14
LS-26	Integument with integrated LSP	424.5	17	6.7
LS-27	LDS 50-01 0.007 psf aluminum	425	18	11.4
LS-28	Integument with integrated LSP	416.5	17	11.2
LS-29	0.016 psf expanded aluminum foil	433	18	12.8
LS-30	0.029 expanded copper foil	425	17	12.3
LS-32	LDS 50-01 0.007 psf aluminum	424.5	18	11.7
LS-33	Integument with integrated LSP	408	16.5	20.4
LS-34	Proprietary Spray Material	362	15	19.3
LS-35	Integument with integrated LSP	429	17	9.2
LS-36	Integument with integrated LSP	425	17.5	8.3
LS-37	LDS 50-01 0.007 psf aluminum	408	17.5	13.6

Table 56 - Panel Details with Peak Current and Voltage (2 of 2)

Panel ID	Lightning Strike Material	Current (A)	Voltage (V)	Resistance (m Ω)
LS-38	Integument with integrated LSP	424.5	17	6.9
LS-39	LDS 50-01 0.007 psf aluminum	425	17.5	10.2
LS-40	Integument with integrated LSP	380	16	21
LS-41	LDS 50-01 0.007 psf aluminum	412	18	14.6
LS-42	LDS 50-01 0.007 psf aluminum	425	18	6.6
LS-43	LDS 50-01 0.007 psf aluminum	425	18	7.4
LS-44	LDS 50-01 0.007 psf aluminum	412	17.5	13.2
LS-45	Polydamp Hydrophobic Melamine with metallized PEEK skin	25.5	45.5	43.4
LS-46	Nanocomp sheet (carbon nanotube)	279	12	42.76
LS-47	Nanocomp sheet (carbon nanotube)	302	13	41.8

Table 57 - Indirect Effects of Lightning Test Results

Lightning strike Protection Material	Average Current (A)	Average Voltage (V)	Average Resistance (mΩ)	Current range (A)	Voltage range (V)	Resistance range (mΩ)
Al Panel	433	18	0.97	433	18	0.97
0.016 psf expanded aluminum foil	429	18	18	424.5-433	18	5.9 - 35.6
0.029 expanded copper foil	320	13	7	424.7-429	17-17.5	8.3-12.3
Integument with integrated LSP	397	17	10	380-429	16-19	6.7-21
LDS 50-01 0.007 psf aluminum	386	16	12	408-425	16.5-18	6.6-21.1
LDS 50-01 0.007 psf aluminum	421	18	20	416-425	17-18	11.7-22.6
Proprietary Spray Material	368	15	26	362-370.5	15-15.5	19.3-37.5
Nanocomp sheet	291	13	42	279-302	12-13	41.8-42.76
None (base panel)	358	15	41.4	358	15	41.4
Polydamp Hydrophobic Melamine with metallized PEEK skin	26	46	43	26	46	43

Table 58 - Current Waveforms Characteristics for Different Lightning Strike Materials

Panel	Lightning protection material	Time for 10% (μs)	Amplitude at 10% (A)	Ratio	Time at max (μs)	Max peak (A)	Time at 50% (μs)	Amplitude 50% (A)	Ratio
Al	Al	0.00	40.00	9	5.77	431	46.55	228.89	53
CFC	None	0.04	35.42	10	4.25	354	15.69	192.62	54
LS-20	Proprietary Spray Material	0.48	36.88	10	4.79	368	14.91	194.01	52
LS-29	0.016 psf expanded aluminum foil	0.66	42.63	10	6.60	426	42.77	222.94	52
LS-2	0.029 expanded copper foil	0.62	42.27	10	6.24	422	40.39	224.84	53
LS-33	Integument with integrated LSP & PSA	0.60	39.15	10	5.99	391	20.62	213.75	54
LS-39	LDS 50-01 0.007 psf aluminum	0.88	42.41	10	8.80	424	42.74	220.17	51
LS-43	LDS 50-01 0.007 psf aluminum	0.71	34.51	10	7.07	345	44.71	187.36	54
LS-47	Nanocomp sheet (15 gsm, 1 layer)	0.33	30.05	10	3.35	300	9.09	158.66	52

Table 59 - Voltage Waveforms Characteristics for Different Lightning Strike Materials

Panel	Lightning protection material	Time for 10% (µs)	Amplitude at 10% (V)	Ratio	Time at max (µs)	Max peak (V)	Time at 50% (µs)	Amplitude 50% (V)	Ratio
Al	Al	0.00	1.68	10	9.59	17	44.95	9.54	54
CFC	None	0.00	1.55	11	2.50	14	15.26	7.71	53
LS-20	Proprietary Spray Material	0.49	1.52	10	4.93	15	16.22	8.08	53
LS-29	0.016 psf expanded aluminum foil	0.70	1.76	10	6.96	17	41.49	9.68	54
LS-2	0.029 expanded copper foil	0.74	1.79	10	7.38	17	45.70	9.14	51
LS-33	Integument with integrated LSP & PSA	0.65	1.61	10	6.47	16	21.46	8.66	53
LS-39	LDS 50-01 0.007 psf aluminum	0.78	1.74	10	7.80	17	41.23	9.41	54
LS-43	LDS 40-03(N) 0.0016 psf nickel coated copper	0.56	2.12	10	5.59	21	42.05	11.45	54
LS-47	Nanocomp sheet (15 gsm, 1 layer)	0.37	1.25	10	3.72	12	9.51	6.78	54

7.3.3 Direct Effects of Lightning

The composite panels were struck using current component D (ARP 5412A (Reference 15) with an amplitude of 100 kA on the protective skin side of the composite panel. The panels were tested according to applicable sections of SAE ARP5416 (Reference 16). In addition, a metal rod and "fuse" wire were installed under the panels to simulate a system (cable bundle, hydraulic line, etc) routed under the skin to determine effects. This configuration was used on all panels. Testing was conducted at DNB Engineering in Fullerton, California. Figure 91 and Figure 92 show a sample of pretest setup and post strike of LS–2.

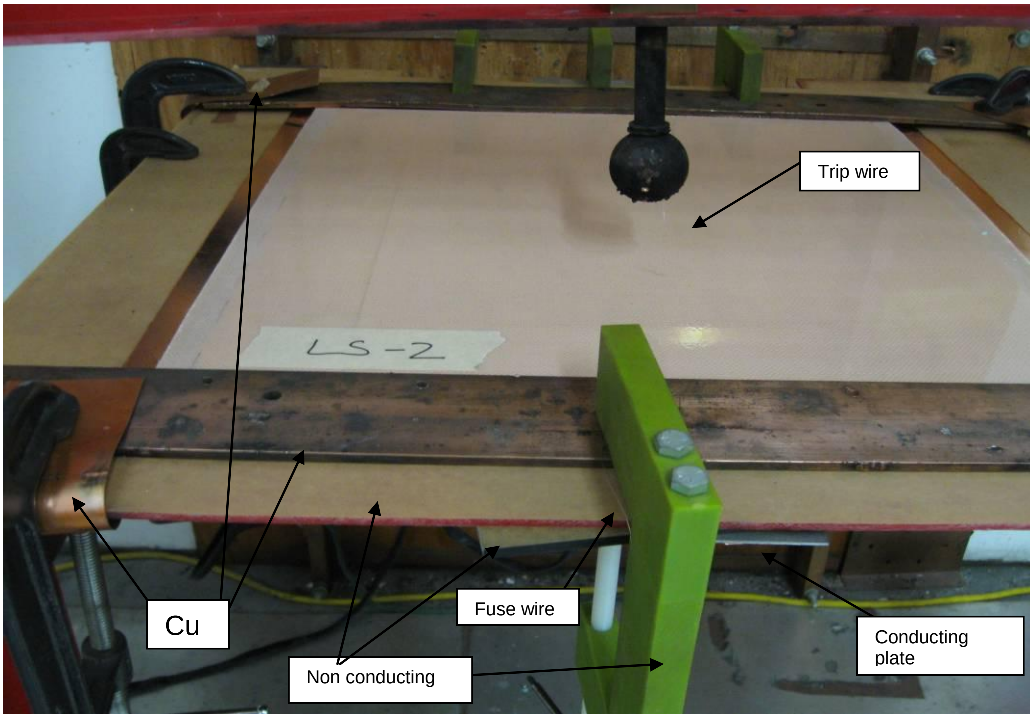


Figure 91: A sample of the setup for direct strike on panel LS-2.

Figure 92: A sample of post strike of 100kA on panel LS-2.

Test results for all panels are shown in Table 60**.** The shaded rows in Table 60 are for the second strike at 200kAmps for three panels. The convention for damage on the panel's inner hole is a hole in the base substrate panel, and outer hole is a hole in the outer layers of the protective skin. Inner delamination (debond and delamination seen in the base substrate panel) and outer delamination (debond seen in the protective skin) were measured with thermography and tap test respectively. Tap tests were done to get an approximate measurement of debond in the core location. The inner delamination number presented is the equivalent diameter of a circle with the area found from the thermography inspection.

Table 60 - Damage and Delamination for All Panels (Post Lightning Strike)

Panel number	Strike	Inner Hole (in)	Inner Delamination (in)	Inner damage (in)	Outer Hole (in)	Outer Delamination (in)	Current (k A)
LS01	1	0	0.00*	0	1.19	1.8	100
LS02	1	0	0.00*	0	0.46	3.6	100
LS04	1	0	0.00*	0	0	7.5	100
LS05	1	0	0.00*	0	0.41	2	100
LS06	1	0	0.00*	0	0.2	3.3	100
LS07	1	0	0.00*	0	0	2.9	100
LS08	1	0	0.00*	0	0.82	4.3	100
LS09	1	0	0.00*	0	0	7.1	100
LS10	1	0	0.00*	0	0.82	1.3	100
LS11	1	0	0.00*	0	0	1.7	100
LS12	1	0	0.00*	0	0.3	2.8	100
LS13	1	0	0.00*	0	0	0	100
LS14	1	0	0.00*	0	0	4	100
LS15	1	0	0.00*	0	1.18	7.7	100
LS16	1	0	0.00*	0	1.96	6	100
LS18	1	0	0.00*	0	0	6	100
LS19	1	0	0.00*	0	2.03	7.1	100
LS20	1	0	**2.47**	0	2.65	9.6	100
LS21	1	0	0.00*	0	0.78	2	100
LS22	1	0	0.00*	0	3.32	3	100
LS23	1	0	0.00*	0	0	9	100
LS24	1	0	0	0	1.6	5.5	100
LS25	1	0	0	0	0.55	7	100
LS26	1	0	0.00*	0	1.56	ALS not bonded properly	100
LS27	1	0	0.00*	0	0	5.2	100
LS28	1	0	0.00*	0	0.81	4.8	100
LS29	1	0	0	0	0.84	6	100
LS30	1	0	**0.78**	0	0.45	4.2	100
LS32	1	0	0.00*	0	0.3	7	100
LS33	1	0	0.00*	0	1.37	3.7	100
LS34	1	0	0.00*	0	0.4	3.2	100
LS34	2	0	0.00*	0	0.4	9.2	**200**
LS35	1	0	0.00*	0	0.1	4.3	100
LS36	1	0	**1.67**	0	1.85	6	100
LS37	1	0	0.00*	0	0.2	9	100
LS38	1	0	**0.84**	0	1.99	4.2	100
LS39	1	0	0.00*	0	0	8.5	100
LS39	2	0	0.00*	0	0	13.5	**200**
LS40	1	0	**2.02**	0	0.27	3.4	100
LS40	2	0	**1.92**	0	0.38	9.4	**200**
LS41	1	0	0.00*	0	0	8.9	100
LS42	1	0	0	0	0	3.9	100
LS43	1	0	0.00*	0	0	6.7	100
LS44	1	0	**0.70***	0	0	3.7	100
LS45	1	0	0	0	0.86	10.5	100
LS46	1	0	**1.68**	0	9	20	100
LS47	1	0	**1.67**	0	9	20	100

*no apparent damage with direct strike in area of porosity

The requirement to pass direct effects of lightning testing is to have no inner hole and no inner delamination (no hole or delamination in the base substrate panel). There is no requirement on outer holes or delamination; the protective skin can be completely gone after a lightning strike. Table 61 shows debond in the carbon fiber composite (laminate) at the back of the core for eight panels; the other 36 did not have evidence of damage. The effect of base substrate panel porosity does appear here in a negative way. There were 34 lightning strike panels where no apparent damage was found, but the direct strike occurred in an area of high porosity, making it impossible to determine if there was actual damage or not. The conservative approach is to assume no damage and keep those materials in consideration for the final set of STAR-C^2 panels.

Table 61 - Panels with Non-Zero Inner Delamination Due to DEL

Panel number	Current (k Amps)	Strike	Inner Delamination	Outer Hole	Outer Delamination	Impact Absorbing Foam Layer	Lightning Strike Material
LS20	100	1	2.47	2.65	9.6	3 pcf metallic honeycomb, 1/4" thick	LORD Spray Material
LS30	100	1	0.78	0.45	4.2	Soric XF, 2mm thick	0.029 expanded copper foil
LS36	100	1	1.67	1.85	6	Soric XF, 2mm thick	LDS 40-03(N) 0.0016 psf nickel coated copper
LS38	100	1	0.84	1.99	4.2	Soric XF, 6mm thick	Integument with integrated LSP
LS40	100	1	2.02	0.27	3.4	Soric LRC, 2 mm thick	Integument with integrated LSP
LS40	**200**	2	1.92	0.38	9.4	Soric LRC, 2 mm thick	Integument with integrated LSP
LS44	100	1	0.7	0	3.7	10# PU core, 1/4" thick	LDS 40-03(N) 0.0016 psf nickel coated copper with Kapton film
LS46	100	1	1.68	9	20	10# PU core, 1/4" thick	Nanocomp sheet
LS47	100	1	1.67	9	20	10# PU core, 1/4" thick	Nanocomp sheet

Table 62 isolates only those eight panels that have been identified as having inner delamination based on thermography report. Inspection through thermography shows panel LS-20 with honeycomb core had the maximum inner delamination of all the panels. LS-46 and LS-47, the carbon nanotube panels, also had significant base substrate panel delamination (not surprising given the violence of what appeared to happen during the lightning strike). Somewhat surprising was panel LS-40. It was struck a second time with 200 k Amps because it appeared to do very well the first time. Thermography showed that it had base substrate panel delamination from both the 100 and the 200kAmp strikes.

Table 62 - Lightning Strike Panels Passing DEL (1 of 2)

Panel ID	Base Panel	Interface	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film	psf
LS-45	7 ply carbon uni epoxy	3M 4950	Polydamp Hydrophobic	None	None	None	None	none	none	0.220
LS-32	7 ply carbon uni epoxy	3M 4950	Soric XF, 2mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.354
LS-33	7 ply carbon uni epoxy	3M 4950	Soric XF, 2mm thick	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.381
LS-29	7 ply carbon uni epoxy	3M 4950	Soric XF, 2mm thick	Aeropoxy	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.387
LS-37	7 ply carbon uni epoxy	3M 4950	Soric XF, 6mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.393
LS-39	7 ply carbon uni epoxy	3M 4950	Soric LRC, 2 mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.399
LS-34	7 ply carbon uni epoxy	3M 4950	Soric XF, 2mm thick	Aeropoxy	Innegra S	None	LORD Spray Material	none	Integument film w/PSA	0.440
LS-35	7 ply carbon uni epoxy	3M 4950	Soric XF, 2mm thick	Aeropoxy	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none	0.446
LS-22	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Tegris LM	None	Integument with integrated LSP & PSA	none	none	0.464
LS-18	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.470
LS-15	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.488
LS-42	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Aptiv PEEK Film w/PSA	0.488
LS-16	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	Aeropoxy	0.029 expanded copper foil	none	Integument film w/PSA	0.494
LS-19	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.500

Table 62 - Lightning Strike Panels Passing DEL (2 of 2)

Panel ID	Base Panel	Interface	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film	psf
LS-41	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	3M 5004	0.506
LS-43	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	3M F9460PC	Halar ECTFE Film	0.506
LS-4	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.530
LS-26	7 ply carbon uni epoxy	3M 4950	6 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.542
LS-28	7 ply carbon uni epoxy	3M 4950	7.9 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.542
LS-21	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none	0.548
LS-25	7 ply carbon uni epoxy	3M 4950	6 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.548
LS-27	7 ply carbon uni epoxy	3M 4950	7.9 pcf metallic honeycomb, 1/4"	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.554
LS-5	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.565
LS-2	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Innegra S	Aeropoxy	0.029 expanded copper foil	none	Integument film w/PSA	0.568
LS-1	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.571
LS-23	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 3/4"	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.598
LS-7	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none	0.601
LS-8	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Tegris LM	None	Integument with integrated LSP & PSA	none	none	0.607
LS-6	7 ply carbon uni epoxy	3M 4950	10# PU core, 1/4" thick (FR-6710)	Aeropoxy	Innegra S	None	LORD Spray Material	none	Integument film w/PSA	0.619
LS-24	7 ply carbon uni epoxy	3M 4950	3 pcf metallic honeycomb, 3/4"	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.625
LS-12	7 ply carbon uni epoxy	3M 4950	20# PU core, 1/4" thick (FR-6720)	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.735
LS-11	7 ply carbon uni epoxy	3M 4950	20# PU core, 1/4" thick (FR-6720)	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.738
LS-9	7 ply carbon uni epoxy	3M 4950	10# PU core, 3/4" thick (FR-6710)	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.935
LS-10	7 ply carbon uni epoxy	3M 4950	10# PU core, 3/4" thick (FR-6710)	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.940
LS-14	7 ply carbon uni epoxy	3M 4950	30# PU core, 1/4" thick (FR-6720)	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.940
LS-13	7 ply carbon uni epoxy	3M 4950	30# PU core, 1/4" thick (FR-6720)	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.964

7.3.4 Electromagnetic Effects Results

Three different electromagnetic effects tests were conducted: 1) transmissivity; 2) indirect effects of lighting; and 3) direct effects of lightning. None of the panels failed transmissivity. None were as good as plain aluminum but all were much better than the base substrate panel with no extra protection. Material thickness was the only property that seemed to have any effect on shielding (transmissivity). The IEL testing failed to produce any conclusive results. The carbon nanotube and Polydamp hydrophobic melamine were identified as having current and voltage results different than the other panels and different than aluminum. Even with that, no conclusions could be drawn. IEL is very configuration sensitive; screening tests are of limited value.

The DEL testing did provide useful data. Eight of the panels failed direct strike testing. The remaining panels are shown in Table 62; the panels are sorted by areal weight. Unlike the impact panels, these panels have all layers of material and represent the total weight of the protective skin. The first page of Table 62 is all of the lightning strike panels with areal weights of 0.500 psf or less (14 panels). At the top of the list is the Polydamp hydrophobic melamine with metalized PEEK skin with an areal weight of 0.220 psf which is less than the target of 0.275 psf. The other panels are all over the target but these 14 are all at or under the upper boundary. Five of the panels which failed were under the upper boundary of 0.5 psf; three were over by a small amount (0.512, 0.521, and 0.530 psf).

The Soric had mixed results. All of the Soric panels had areal weights less than 0.5 psf. Five of the panels with Soric XF 2 mm passed lightning strike; two of the panels with Soric XF 2 mm failed lightning strike. The panels which failed had a combination of Innegra and Tegris; the panels which passed had a combination of Innegra and carbon epoxy. Integument with integrated LSP and PSA failed as often as it passed on the 2 mm Soric XF. One Soric XF 6 mm panel passed and one failed; the difference was LDS 50-01 LSP with Integument film on the panel that passed and Integument film with integrated LSP and PSA on the panel that failed. One Soric LRC 2mm panel passed and one failed. The one that passed had Innegra with LDS 50-01 and Integument film. The panel that failed had Innegra with Integument with integrated LSP and PSA. There were no lightning strike panels with the 3mm Soric LRC.

All but one of the other panels which failed all had areal weights greater than 0.5 psf. The exception was panel LS-44 which was ¼” thick 10 pcf polyurethane core with Innegra, LDS 50-01 LSP, and Kapton. Another of the panels which failed had 3 pcf ¼” thick metallic honeycomb with LORD spray material and Integument film.

In general, Soric may be a good material, Innegra did extremely well, the LDS 50-01 did well and was light, and the Integument film with PSA did a respectable job. These results, when combined with the impact results and the aesthetics and smoothing results, will provide guidance on the final materials and panel matrix for the second generation of STAR-C^2 protective skins.

7.4 Aesthetics and Smoothing

There were three primary areas of aesthetics and smoothing tests: 1) visual inspection of the 30 aesthetics and smoothing (AS-1 to AS-30) test articles after installing each protective skin over a base substrate panel containing multiple geometric features; 2) visual inspection of the lightning strike panels; and 3) thermal testing. The testing and test results will be described in the following subsections.

7.4.1 Smoothness

The material combinations used for impact energy absorption, impact energy spreading, lightning strike protection and aesthetics and smoothing as listed in Table 19 were combined into single piece stack-ups prior to being applied to the modified base substrate panels (drawing shown in Figure 93). These material stack-ups each included a layer of 3M 4950 VHB tape, which was used to attach the stack-ups to the base substrates. A special fixture was constructed (Figure 94) and a pressure roller was used to consistently attach the protective skin panels to the base substrate panels (Figure 95).

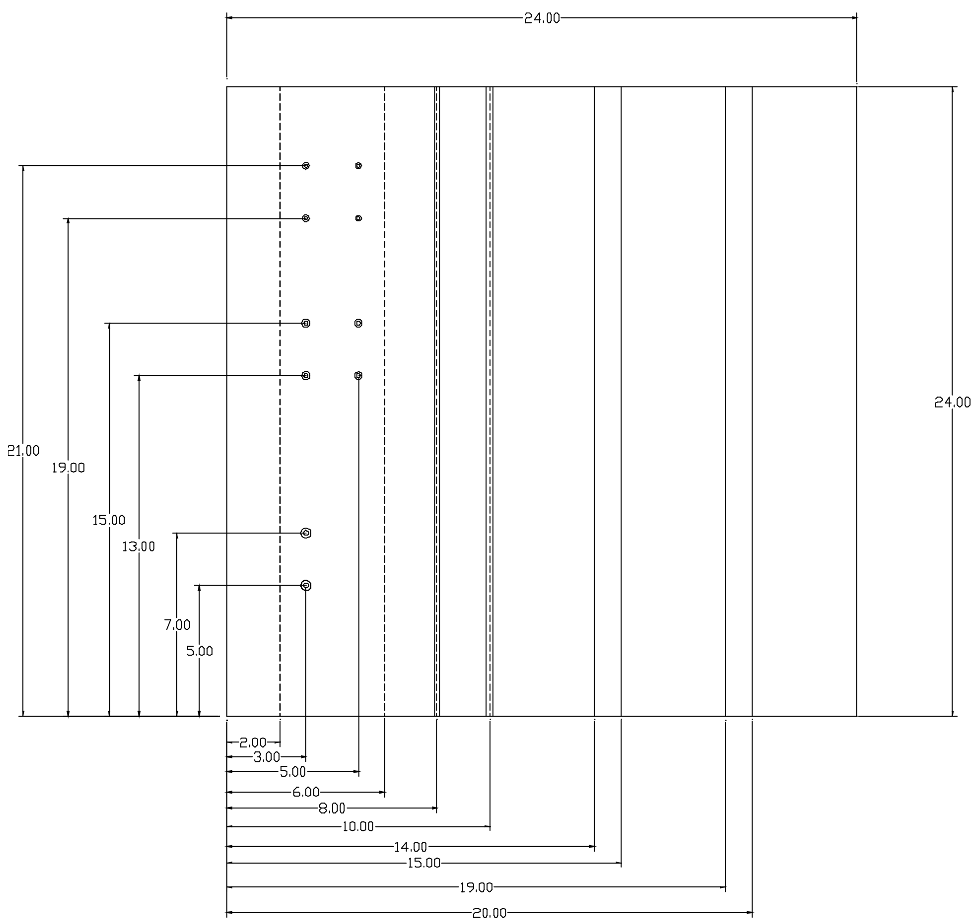


Figure 93: Base substrate for aesthetic and smoothing test panels showing fasteners, wire bundles, and doublers.

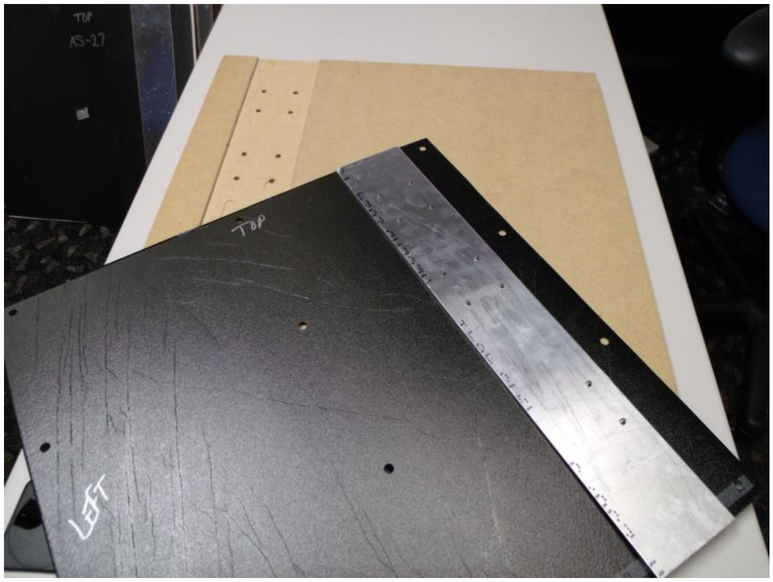


Figure 94: Aesthetic and smoothing base substrate panel holder.

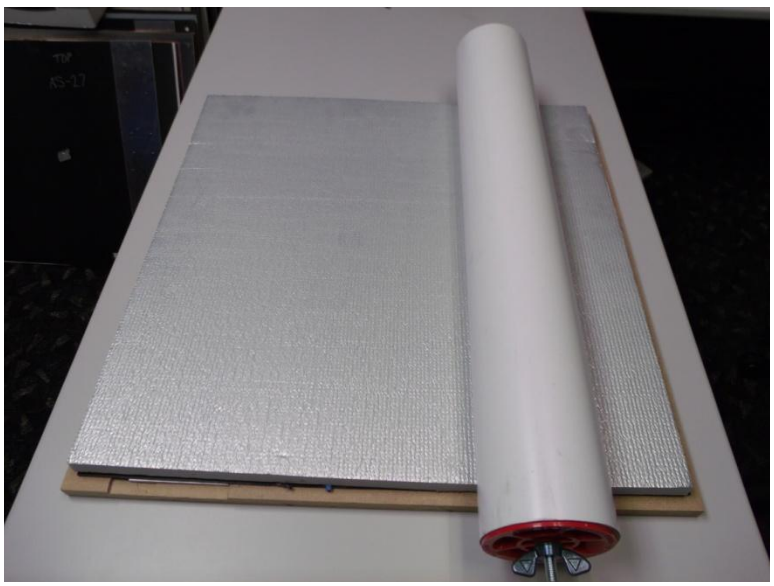


Figure 95: Application of stack-up with pressure roller.

The test plan for the aesthetic and smoothing test panels originally called for ATOS white light scans of the outer surface of the completed panels to assess any surface deviations that resulted from the underlying geometric features on the modified base substrates. During and after the application of the material stack-ups, it was noted that the stiffness of most of the stack-ups was significantly higher than the base substrate panels. As a result, after application, for most panels, the stack-ups produced significant deformation of the base substrate and the geometric features were not uniquely translated to the outer aesthetic layer. Therefore, the ATOS white light scan data would have been of limited usefulness, because much of the deformation at the surface was also impacted by the deformation of the underlying structure. In order to gain some useful data with which to analyze the effectiveness of the

stack-ups for aesthetics and smoothing, notes from visual examinations of the panels were recorded, a number of physical measurements of the panels were taken, and photographs of the panels were captured.

As data was collected, it became clear that the performance trends were largely influenced by the combinations of impact absorbing layer materials and energy absorbing material layers, rather than by the aesthetic and smoothing layer. As a result, the results presented will tend to be grouped by the impact spreading and energy absorbing layers first, with aesthetic and smoothing films secondary. The end result of this is that the panel identification numbers are out of sequence, because the test matrix was arranged with the aesthetic and smoothing layer materials as the primary variable and the others secondary.

The visual indications that were recorded consisted of whether or not the various fasteners were visible at the outer layer, whether the dowel rods were visible, either from local deformation or a global perspective, and whether the 0.020" and 0.040" aluminum doublers were visible at the surface. The summary from the visual examinations are presented in Tables 63 through 67. As can be seen in the tables, none of the combinations investigated completely covered the surface geometry deviations, without some translation to the surface. For the stiffer combinations, the dowels on the surface created global deformations of the stack-ups that resulted in the materials not contacting the base panel between them. Most of the panels did fairly well hiding the flush and smaller size protruding fasteners, with only a few showing the largest -6 protruding head fasteners at the outer surface.

From a purely cosmetic standpoint, there was little difference between the polyurethane, metallic honeycomb and non-metallic honeycomb panels, as can be seen in Tables 63, 64, and 65. Table 66 shows that the Polydamp hydrophobic melamine cores did not perform very well in hiding the doublers or fasteners when tested at ½" thick, but at ¾" thick, they hid both the fasteners and doublers quite well. The Polydamp core also performed differently than all of the other cores with respect to the dowels, in that it compressed over the dowel and was conformal enough that it did attach to the base substrate panel between them, although this did cause some wrinkling at the outer surface and the dowels could be seen as a local deformation at the outer surface of the panel as well. Finally, Table 67 shows that the Soric core based panels did not perform well in their ability to hide any of the surface geometric features on the base substrates.

Table 63 - Visual Examination Results for Polyurethane Core Panels

Panel ID:	AS-1	AS-6	AS-11	AS-16	AS-21	AS-26
Core Material:	FR6710 1/4"	FR6710 1/4"	FR6710 1/4"	FR6710 1/4"	FR6710 1/4"	FR6710 1/4"
Impact Spreading Layer:	Innegra	Innegra	Innegra	Innegra	Innegra	Innegra
Aesthetic Layer:	Integument	Integument with ALS	3M 5004	Aptiv PEEK	Halar	Kapton
-4 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-6 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Visible
-4 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Flush	Not visible	Not visible	Not visible	Not Visible	Not visible	Not visible
0.1875" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.25" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.020" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.040" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible

Table 64 - Visual Examination Results for Non-metallic Honeycomb Core Panels

Panel ID:	AS-2	AS-7	AS-12	AS-17	AS-22	AS-27
Core Material:	4 PCF Nomex 1/2"	4 PCF Nomex 1/2"	4 PCF Nomex 1/2"	4 PCF Nomex 1/2"	4 PCF Nomex 1/2"	4 PCF Nomex 1/2"
Impact Spreading Layer:	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum
Aesthetic Layer:	Integument	Integument with ALS	3M 5004	Aptiv PEEK	Halar	Kapton
-4 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-6 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Visible
-4 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.1875" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.25" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.020" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.040" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible

Table 65 - Visual Examination Results for Metallic Honeycomb Core Panels

Panel ID:	AS-3	AS-8	AS-13	AS-18	AS-23	AS-28
Core Material:	6 PCF Metallic 1/4"	6 PCF Metallic 1/4"	6 PCF Metallic 1/4"	6 PCF Metallic 1/4"	6 PCF Metallic 1/4"	6 PCF Metallic 1/4"
Impact Spreading Layer:	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum	0.012" aluminum
Aesthetic Layer:	Integument	Integument with ALS	3M 5004	Aptiv PEEK	Halar	Kapton
-4 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Visible	Not Visible
-6 Protruding	Not Visible	Not Visible	Not Visible	Not Visible	Visible	Not Visible
-4 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.1875" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.25" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.020" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.040" Al Doubler	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible

Table 66 - Visual Examination Results for Polydamp Core Panels

Panel ID:	AS-9	AS-14	AS-19	AS-29	AS-4	AS-24
Core Material:	Polydamp 1/2"	Polydamp 1/2"	Polydamp 1/2"	Polydamp 1/2"	Polydamp 3/4"	Polydamp 3/4"
Impact Spreading Layer:	None	None	None	None	None	None
Aesthetic Layer:	Integument with ALS	3M 5004	Aptiv PEEK	Kapton	Integument	Halar
-4 Protruding	Not Visible	Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Protruding	Not Visible	Visible	Not Visible	Not Visible	Not Visible	Not Visible
-6 Protruding	Not Visible	Not Visible	Visible	Not Visible	Not Visible	Not Visible
-4 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
-5 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.1875" Dowel	Individually Visible	Individually Visible	Individually Visible	Individually Visible	Individually Visible	Individually Visible
0.25" Dowel	Individually Visible	Individually Visible	Individually Visible	Individually Visible	Individually Visible	Individually Visible
0.020" Al Doubler	Not Visible	Not Visible	Visible	Not Visible	Not Visible	Not Visible
0.040" Al Doubler	Not Visible	Visible	Visible	Visible	Not Visible	Not Visible

Table 67 - Visual Examination Results for Soric Core Panels

Panel ID:	AS-5	AS-10	AS-15	AS-20	AS-25	AS-30
Core Material:	Soric XF 2mm	Soric XF 2mm	Soric XF 2mm	Soric XF 2mm	Soric XF 2mm	Soric XF 2mm
Impact Spreading Layer:	Innegra	Innegra	Innegra	Innegra	Innegra	Innegra
Aesthetic Layer:	Integument	Integument with ALS	3M 5004	Aptiv PEEK	Halar	Kapton
-4 Protruding	Visible	Visible	Visible	Visible	Visible	Visible
-5 Protruding	Visible	Visible	Visible	Visible	Visible	Visible
-6 Protruding	Visible	Visible	Visible	Visible	Visible	Visible
-4 Flush	Visible	Not Visible	Visible	Visible	Not Visible	Not Visible
-5 Flush	Visible	Not Visible	Visible	Visible	Not Visible	Not Visible
0.1875" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.25" Dowel	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible	Globally Visible
0.020" Al Doubler	Visible	Visible	Visible	Visible	Visible	Visible
0.040" Al Doubler	Visible	Visible	Visible	Visible	Visible	Visible

In order to further characterize these panels, physical measurements were taken for the following parameters:

- Panel deformation
- Panel thickness over the 0.020” thick doubler
- Panel thickness over the 0.040” thick doubler
- Panel thickness over the 0.1875” dowel
- Panel thickness over the 0.25” dowel

The overall panel deformation was measured by placing the panels on a flat table with the outer layer face down. The maximum height of the backside of the panel was measured along the bottom edge of the panel, and its height and location from the left edge were recorded. For characterization and data analysis, the nominal panel thickness was subtracted from the recorded value, to arrive at a computed value for the distance between the table and the outer layer of the panel. This value was compared across the various panel combinations and is shown in Figure 96.

The panel thicknesses over the two dowels and two doublers were all measured with a digital caliper. For reporting purposes, the nominal thickness of the panel was subtracted from the recorded value, as was the thickness of the particular item at each location. The resulting values were used in the comparisons of the different panel configurations as shown in Figure 96 through Figure 100.

As can be seen in Figure 96, the largest panel deformations are related to the non-metallic honeycomb core. The deflections for the metallic honeycomb, polyurethane, and Soric cores are not significantly different, implying that the stiffness of those panels is similar and lower than the stiffness of the non-metallic honeycomb cores. The Polydamp cores are the least stiff of the stack-ups and therefore have the lowest amount of overall panel deformation. Further of note is that the results are relatively insensitive to the aesthetic layer used, with the energy absorbing and impact spreading layer combinations being the major dependant variable in the panels.

Similarly, Figure 97 and Figure 98 show the results for the 0.020” and 0.040” aluminum doublers, respectively. For the most part, the panels show small increases over the doublers, although it is noted that no allowance was made mathematically for the paste adhesive bonding thickness used to bond the doublers to the base panels. The few negative thickness values associated with some of the Polydamp panels are indicative of the compressibility of the melamine foam over the surface deviations. The relatively large data scatter associated with the Polydamp samples is attributed to the difficulty of measuring a soft compressible foam core with a caliper.

Finally, Figure 99 and Figure 100 show the results of the 0.1875” and 0.25” diameter dowels that were used to mimic potential wire bundle configurations on the outer surface of the structure. As was seen earlier in the visual examination results, the global deformation of the outer surfaces of the more stiff panels shows fairly consistent results for the metallic honeycomb, non-metallic honeycomb, polyurethane and Soric cores, with substantially different results for the Polydamp compares to all of the others. Similar to the aluminum doublers, the negative values for the Polydamp-based panels are representative of the compressibility of the melamine foam over these surface deviations. For the most part, the other cores showed relatively small deviations over the 0.1875” dowels, with the exception of the stiffest panels

based on the non-metallic honeycomb cores. For those panels, the increase deformation is likely representative of the fact that the panels were not in direct contact with the 0.1875" dowels after being pushed further away by the 0.25" dowel offset. Figure 100 shows additional negative deformation values for other cores than the Polydamp, which may be attributable to local core crushing over this feature, which was the tallest out-of-plane feature that existed on the panels.

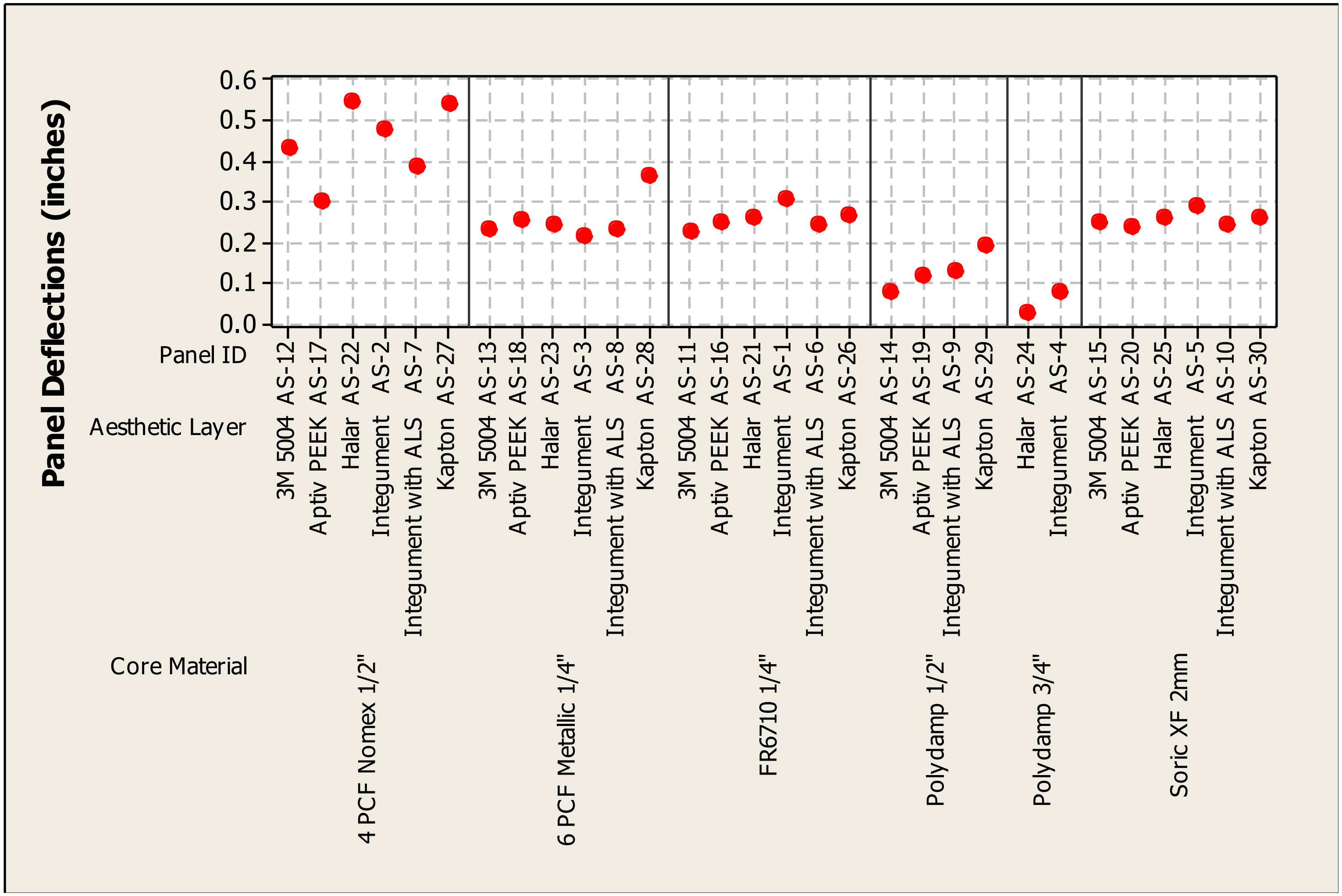


Figure 96: Computed maximum panel deformation.

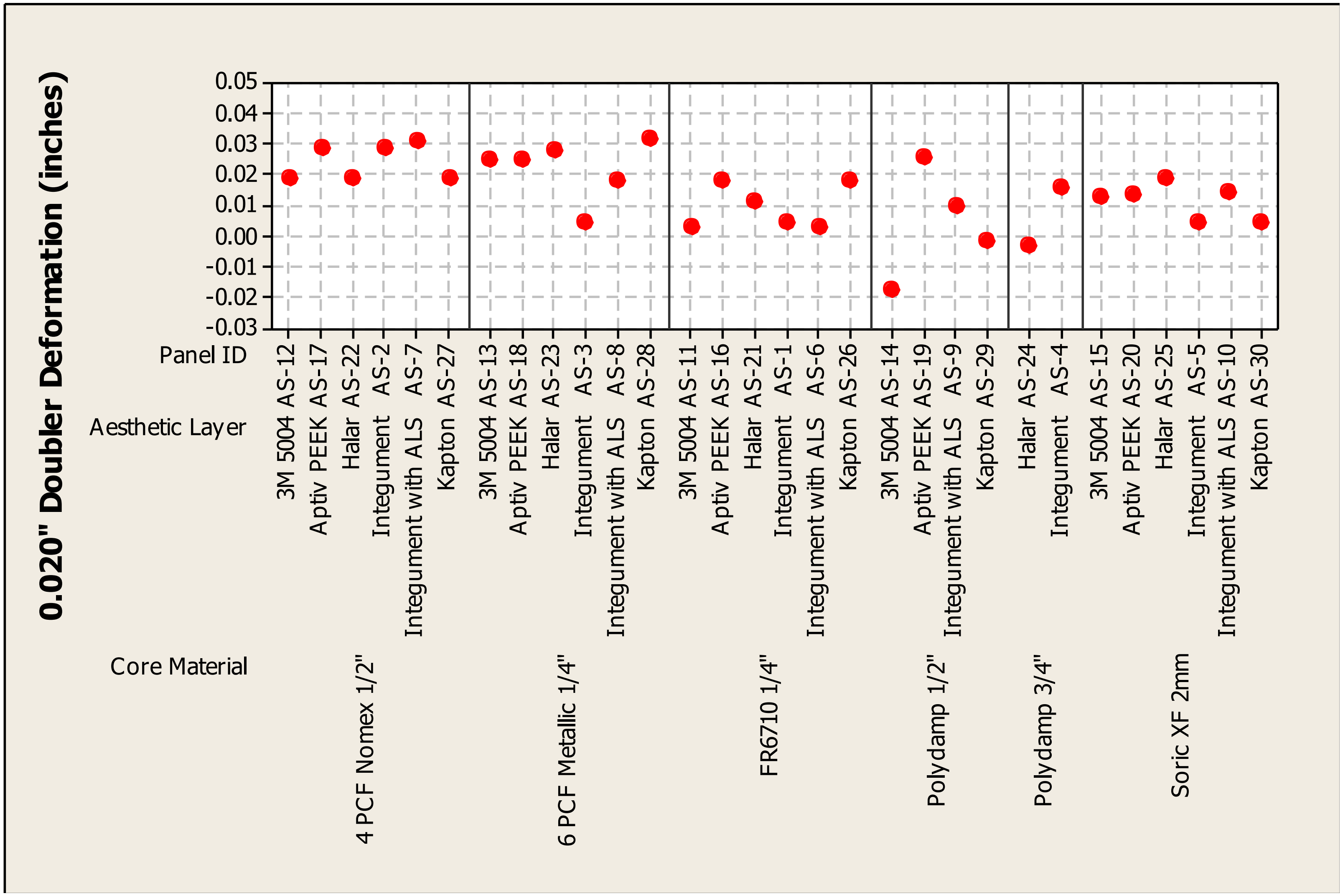


Figure 97: Computed deformation over 0.020" doubler.

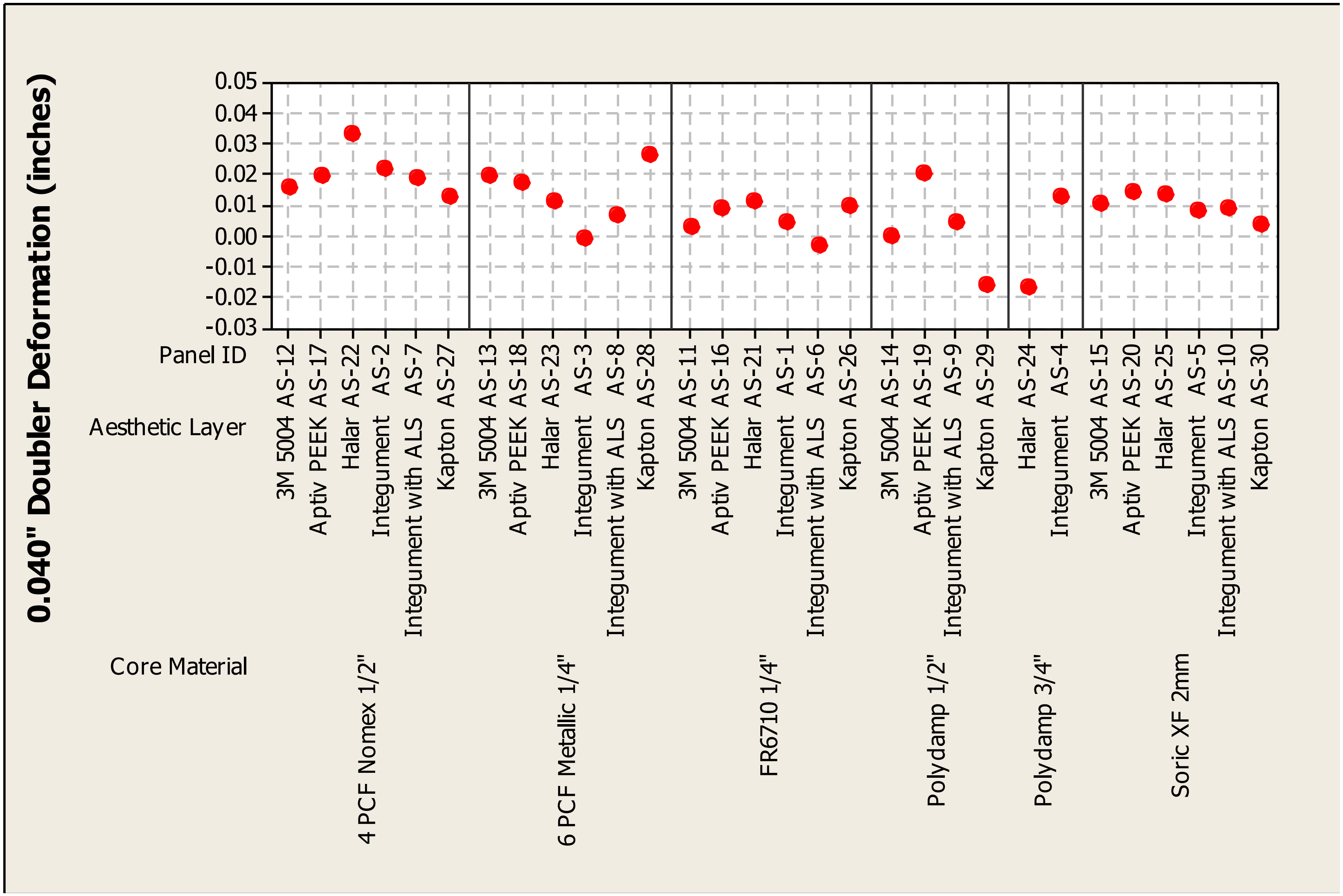


Figure 98: Computed deformation over 0.040” doubler.

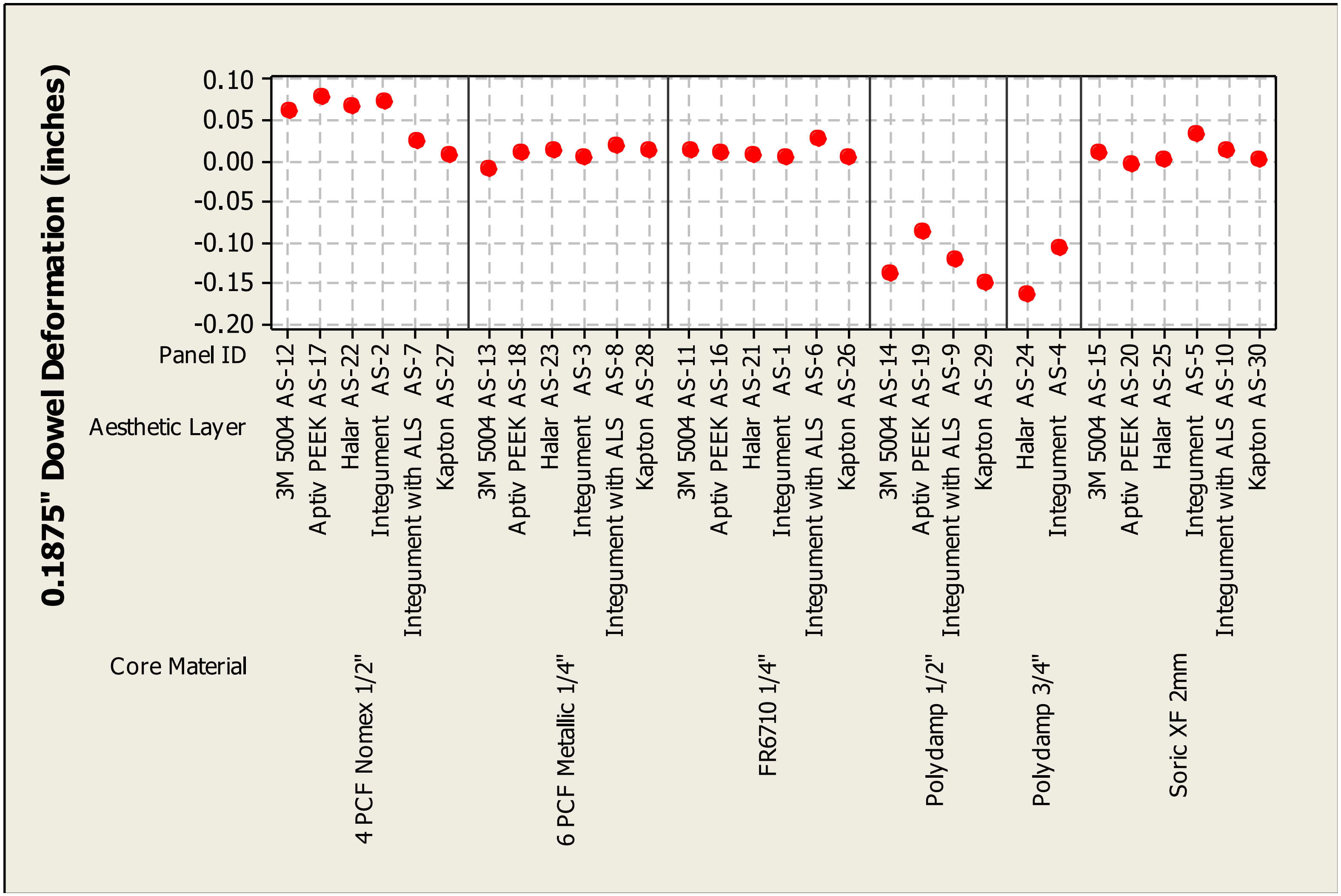


Figure 99: Computed deformation over 0.1875” dowel.

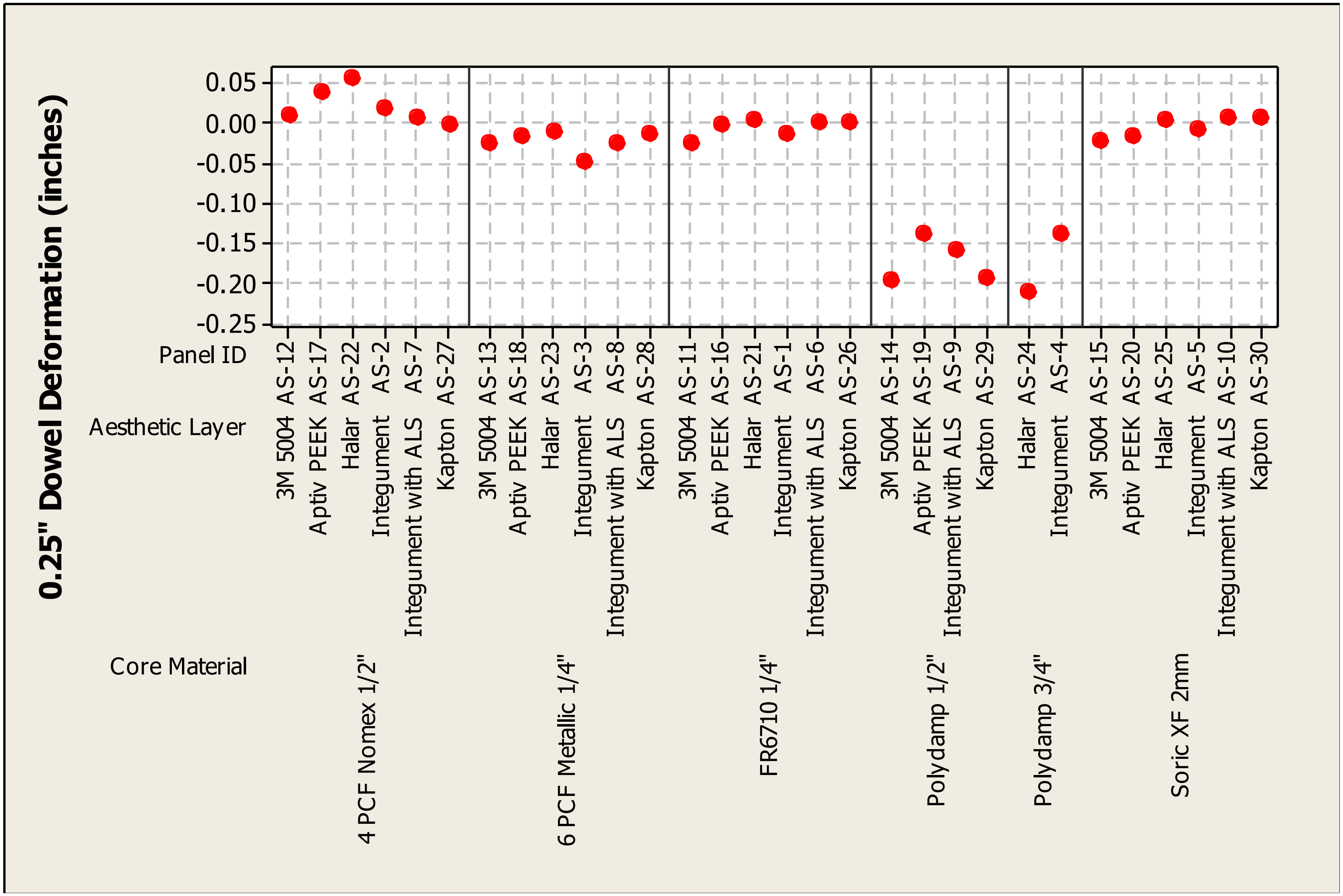


Figure 100: Computed deformation over 0.25" dowel.

7.4.2 Lightning Strike Panel Visual Inspection

The panels fabricated for the direct and indirect effects of lightning testing were visually examined for outer layer surface anomalies prior to being subjected to their associated lighting strike tests. The results of these examinations are captured in **Error! Not a valid bookmark self-reference.** through Table 70.

For the metallic honeycomb cores, the core was first stabilized with film adhesive prior to placing the outer layers over it. For several of the panels, the film stabilized side of the core was incorrectly placed against the foam VHB tape rather than the impact spreading layer. These panels are identified with an asterisk in the Core/Impact Spreading column of **Error! Not a valid bookmark self-reference.**. In general, the metallic honeycomb-based panels shown in **Error! Not a valid bookmark self-reference.** had relatively smooth outer surfaces that were free of bubbles and wrinkles. The two lighter densities (3.4 pcf and 6 pcf) exhibited the core pattern at the outer surface, regardless of the impact spreading layer, lightning strike layer, and aesthetic layer materials that were used. The highest density core (7.9 pcf) was not found to show the core pattern at the surface.

The results of the polyurethane based core panels are shown in Table 69. For the most part, these panels were not as smooth as those built with metallic honeycomb core. There were a number of panels that exhibited bubbles and wrinkles. Several of these panels used materials that were not used in the panels with metallic honeycomb cores, specifically, the Halar and Kapton aesthetic layer materials. These materials were not supplied with pressure sensitive adhesives already applied so a layer a transfer tape was applied to them during the material manufacture. Most of the bubbles and wrinkles seen in these panels were a result of the transfer tape application, but nonetheless were significant in the visual aesthetic evaluation. Overall, the polyurethane cores are smooth on the outer surface, and while there was no overall honeycomb core-type features projected to the surface, there were several panels with a wavy or wrinkled outer surface as well as several that showed the fabric weave pattern of the Innegra impact spreading layer on the outer surface.

Finally, Table 70 shows the results of the lightning strike panels built with Soric core as well as the panel built with the Polydamp hydrophobic melamine core. Overall the Soric core panels exhibited smooth outer surface layers that were free of bubbles and wrinkles. Visual indication showed that the impact spreading layer fabric weave patterns as well as the Soric core cell patterns were visible at the outer surface. Whether this is a visual or physical phenomenon is hard to determine, but based on other investigations on the aesthetic and smoothing panels, it is believed to be a visual phenomenon related to transparent films. The Polydamp-based panel did not contain bubbles, but was wrinkled on the outer surface due to the nature of the material. The aesthetics and smoothing panels with Polydamp had similar surface anomalies, but they were not as prevalent in those panels because of the presence of the additional aesthetic layer materials providing additional support to the outermost surfaces.

Table 68 - Visual Examination Results for Lightning Strike Panels with Metallic Honeycomb Cores

Panel ID	Core Material	Impact Spreading Layer	Lightning Strike Layer	Aesthetic Layer	Smoothness	Bubbles	Wrinkles	Core / Impact Spreading
LS-21	3.4 PCF Metallic 1/4"	Carbon Epoxy	Integument with ALS	Integument with ALS	Smooth	No	No	Core*
LS-15	3.4 PCF Metallic 1/4"	Innegra	0.016 psf Al	Integument	Smooth	No	No	Core*
LS-16	3.4 PCF Metallic 1/4"	Innegra	0.029 psf Cu	Integument	Smooth	No	No	Core*
LS-19	3.4 PCF Metallic 1/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core*
LS-18	3.4 PCF Metallic 1/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	Core
LS-20	3.4 PCF Metallic 1/4"	Innegra	LORD Spray	Integument	Smooth	No	No	Core
LS-22	3.4 PCF Metallic 1/4"	Tegris	Integument with ALS	Integument with ALS	Smooth	No	No	Core*
LS-24	3.4 PCF Metallic 3/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core*
LS-23	3.4 PCF Metallic 3/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	Core
LS-26	6 PCF Metallic 1/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core*
LS-25	6 PCF Metallic 1/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	Core
LS-28	7.9 PCF Metallic 1/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	No
LS-27	7.9 PCF Metallic 1/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	No

Table 69 - Visual Examination Results for Lightning Strike Panels with Polyurethane Cores

Panel ID	Core Material	Impact Spreading Layer	Lightning Strike Layer	Aesthetic Layer	Smoothness	Bubbles	Wrinkles	Core / Impact Spreading
LS-7	FR6710 1/4"	Carbon Epoxy	Integument with ALS	Integument with ALS	Smooth	No	No	Fabric Weave
LS-1	FR6710 1/4"	Innegra	0.016 psf Al	Integument	Smooth	No	No	No
LS-2	FR6710 1/4"	Innegra	0.029 psf Cu	Integument	Smooth	No	No	No
LS-5	FR6710 1/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	No
LS-41	FR6710 1/4"	Innegra	LDS 50-01	3M 5004	Smooth	No	No	No
LS-42	FR6710 1/4"	Innegra	LDS 50-01	Aptiv PEEK	Smooth	No	No	No
LS-43	FR6710 1/4"	Innegra	LDS 50-01	Halar	Ripples, patches	Yes	No	No
LS-4	FR6710 1/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	No
LS-44	FR6710 1/4"	Innegra	LDS 50-01	Kapton	Bubbles	Yes	No	No
LS-6	FR6710 1/4"	Innegra	Proprietary Spray	Integument	Smooth	No	No	No
LS-46	FR6710 1/4"	Innegra	Nanocomp 10 gsm	Integument	Not Smooth	No	No	Fabric Weave
LS-47	FR6710 1/4"	Innegra	Nanocomp 15 gsm	Integument	Not Smooth	No	No	Fabric Weave
LS-8	FR6710 1/4"	Tegris	Integument with ALS	Integument with ALS	Smooth	No	No	No
LS-10	FR6710 3/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	No
LS-9	FR6710 3/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	No
LS-12	FR6720 1/4"	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Fabric Weave
LS-11	FR6720 1/4"	Innegra	LDS 50-01	Integument	Smooth	No	No	No
LS-14	FR3730 1/4"	Innegra	Integument with ALS	Integument with ALS	Wrinkled	No	No	Fabric Weave
LS-13	FR3730 1/4"	Innegra	LDS 50-01	Integument	Not Smooth	No	Yes	Fabric Weave

Table 70 - Visual Examination Results for Lightning Strike Panels with Soric and Polydamp Melamine Cores

Panel ID	Core Material	Impact Spreading Layer	Lightning Strike Layer	Aesthetic Layer	Smoothness	Bubbles	Wrinkles	Core / Impact Spreading
LS-40	Soric LRC 2 mm	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core / Fabric
LS-39	Soric LRC 2 mm	Innegra	LDS 50-01	Integument	Smooth	No	Yes	Core / Fabric
LS-35	Soric XF 2 mm	Carbon Epoxy	Integument with ALS	Integument with ALS	Smooth	No	No	Core / Fabric
LS-29	Soric XF 2 mm	Innegra	0.016 psf Al	Integument	Smooth	No	No	Core / Fabric
LS-30	Soric XF 2 mm	Innegra	0.029 psf Cu	Integument	Smooth	No	No	Core / Fabric
LS-33	Soric XF 2 mm	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core / Fabric
LS-32	Soric XF 2 mm	Innegra	LDS 50-01	Integument	Smooth	No	No	Core / Fabric
LS-34	Soric XF 2 mm	Innegra	LORD Spray	Integument	Smooth	No	No	Core / Fabric
LS-36	Soric XF 2 mm	Tegris	Integument with ALS	Integument with ALS	Smooth	No	No	Core / Fabric
LS-37	Soric XF 6 mm	Innegra	LDS 50-01	Integument	Smooth	No	No	Core / Fabric
LS-38	Soric XF 6 mm	Innegra	Integument with ALS	Integument with ALS	Smooth	No	No	Core / Fabric
LS-45	Polydamp 3/4"	None	None	None	Not Smooth	No	No	Wrinkles

7.4.3 Thermal Testing Results

Thermal analysis testing was performed on the aesthetic and smoothing panels in order to characterize how the material stack-ups would perform as thermal insulation. In order to support this testing, a test fixture was fabricated and mounted in the door opening of a Blue M convection laboratory oven. The test fixture was mounted into the opening through the use of several rare earth magnets and was sealed against the internal frames of the oven to prevent air leaks. An opening allowed for the panels to be mounted into the fixture through the use of a ring doubler and toggle clamps. A surface thermocouple was placed on the back surface of the mounted test panel, and the temperature rise over time was recorded. Additional thermocouples were mounted to aluminum plates and placed adjacent to the oven and in the oven, so that ambient and oven air temperatures could be recorded respectively. The test setup is shown in Figure 101 through Figure 103.

Prior to running a test, the oven was pre-heated to 160°F with a cover plate over the fixture opening. Once stabilized, a test panel was loaded into the fixture, and the digital data recorder for the

thermocouples was started. Once the back-side temperatures of the panels stabilized, the recording was stopped and the process was repeated with the next panel. Throughout all of the thermal testing of the panels, the oven temperature remained within ±5° of the 160°F set point, and the ambient room temperature was fairly consistent.

While testing the aesthetics and smoothing panels, the overwhelming dependant variables in thermal performance were found to be the combination of impact spreading layer and energy absorbing layer. In order to understand some of the other material combinations that were not represented in the aesthetics and smoothing panel matrix, several lightning strike panel combinations were also tested for thermal performance.

Figure 104 shows a sample graphical plot of the data generated for the polyurethane core panels. Similar data was generated from the remainder of the aesthetics and smoothing panels. The steady state temperatures varied along with the rate at which the maximum temperature was reached. The data gathered shows that the thermal performance was not sensitive to the outer aesthetic and smoothing layer, again showing the energy absorbing and impact spreading layers to be the larger contributing factors to a panel's performance. Due to the structure of the panels fabricated for this effort, it was not possible to separate the contribution of the energy absorbing core from the impact spreading layer, but it is theorized that most of the differences in the thermal performance from one series of panels to the next was due to the energy absorbing core more than the impact spreading layers.

Table 71 summarizes the data for all panels tested. The unmodified base substrate showed a maximum temperature of 125.4°F. The best performing cores were the ¾" Polydamp melamine foam with a maximum temperature of 90.7°F, followed by the ½" thick Polydamp melamine foam with a maximum temperature of 95.5°F. The third best performing material of those tested was the ½" thick non-metallic honeycomb material with a maximum of 97.7°F. The worst performing materials in the thermal test were the ¼" thick metallic honeycomb-based panels and the Soric XF 2mm thick cores, all which had temperatures over 115°F.

Figure 101: Thermal performance test setup – mounting frame.

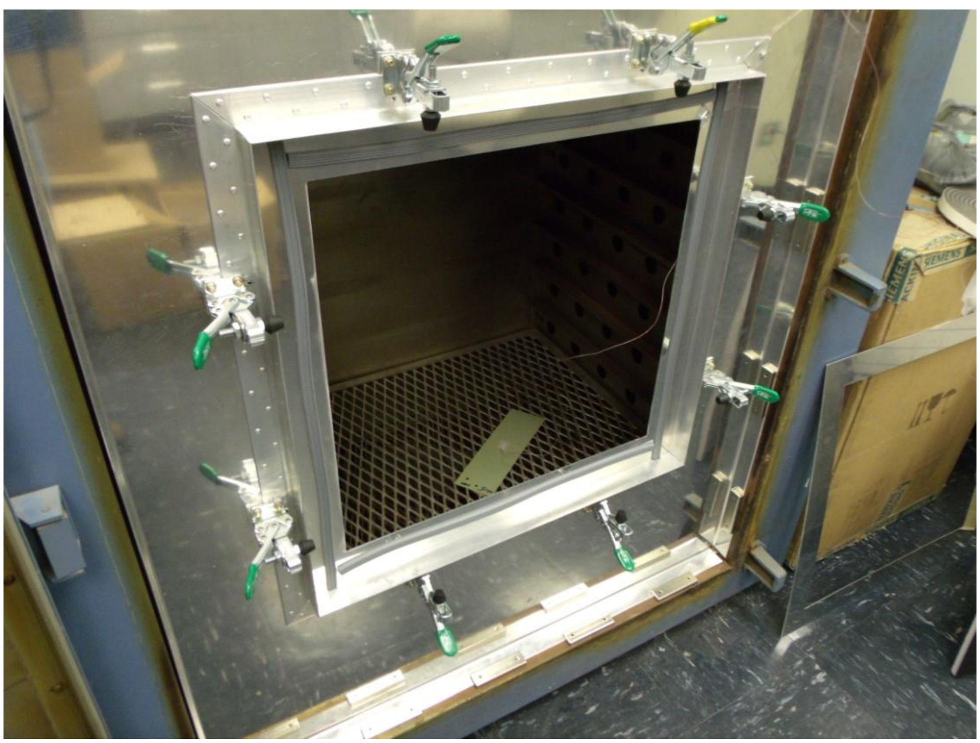


Figure 102: Thermal performance test setup – oven temperature.

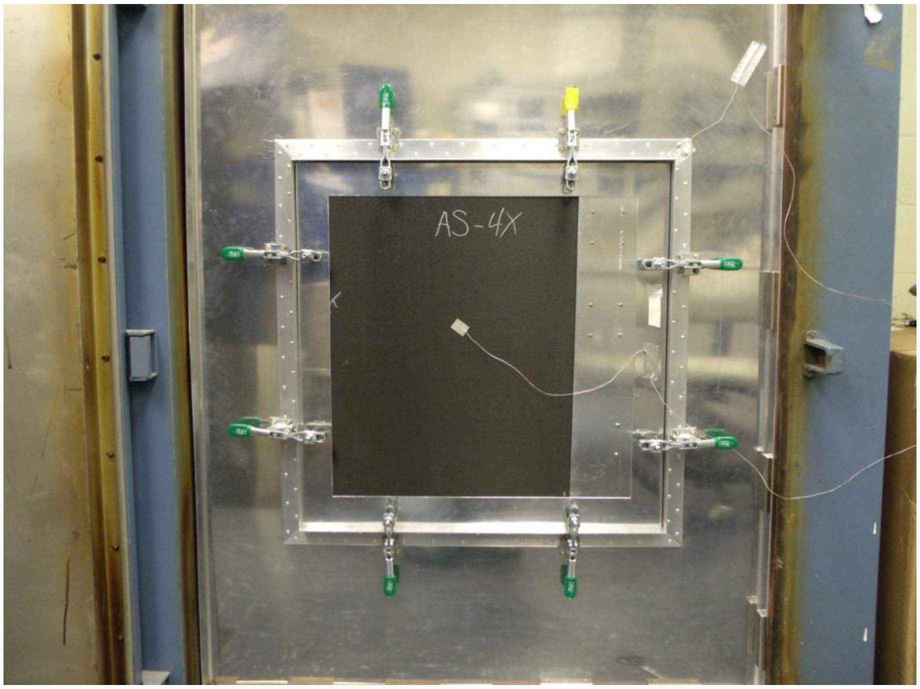


Figure 103: Thermal performance test setup – test in progress.

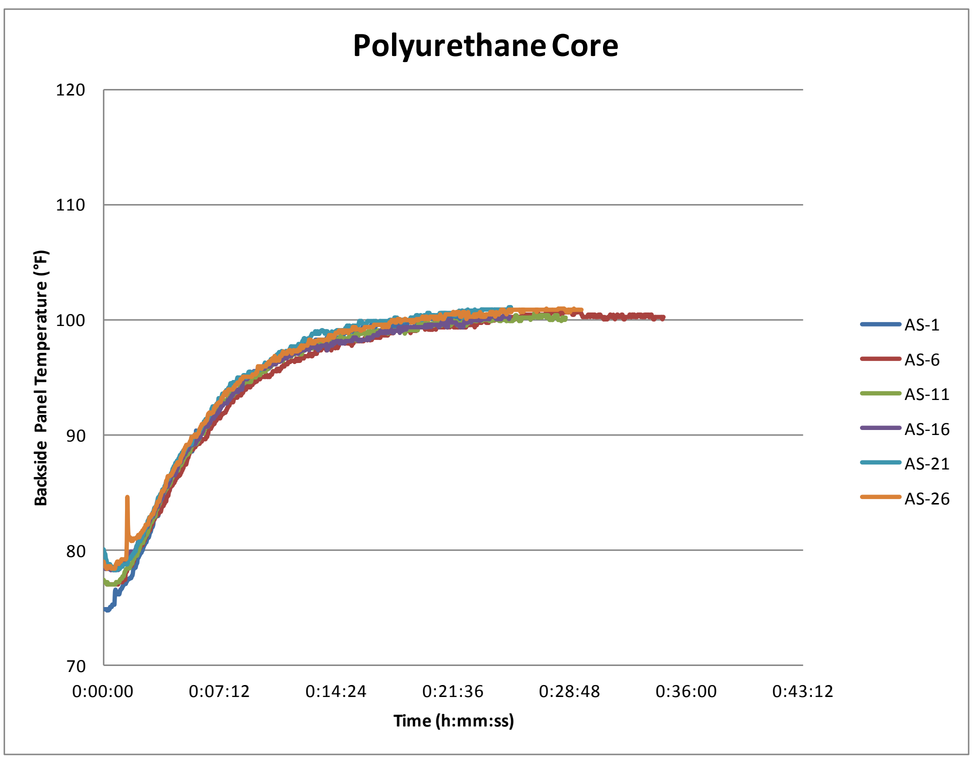


Figure 104: Thermal performance of polyurethane core panels.

Table 71 - Summary of First-Generation Test Article Thermal Performance Trends from Aesthetic and Smoothing, Lightning Strike, and Baseline Panels

Panel ID	Core Type	Max. Temp. (°F)
Average	Baseline Panel	125.4
Average	Soric XF, 2mm thick	115
Average	Metallic Honeycomb, 6 pcf, ¼” thick	110.5
Average	Polyurethane, 10 pcf, ¼” thick	101.1
Average	Non-Metallic Honeycomb, 4 pcf, ½” thick	97.7
Average	Polydamp, ½” thick	95.5
Average	Polydamp, ¾” thick	90.7
LS-11	Polyurethane, 20 pcf, ¼” thick	108.7
LS-13	Polyurethane, 30 pcf, ¼” thick	109.8
LS-18	Metallic Honeycomb, 3 pcf, ¼” thick	115.3
LS-27	Metallic Honeycomb, 9 pcf, ¼” thick	116.8
LS-37	Soric XF, 6 mm thick	100.6

7.5 Implications for Final STAR-C^2 Panels

7.5.1 Combined Test Results

Impact and direct effects of lightning testing identified panels which passed the testing requirements. The combined impact/lightning strike test results (using the lightning strike panels) are shown in Table 72. The impact panels did not have the lightning strike protection (LSP) or the aesthetic film. The next phase of testing will confirm or refute the hypothesis that the LSP and aesthetic film will not contribute significantly to the panel’s ability to meet the impact requirements.

Panels which passed both tests are shown in Table 72 with no shading. Panels which failed lightning strike have grey shading and lines through the text. Panels which failed impact testing are shown with mauve highlighting. Panels which failed both lightning strike and impact are shown with rotating grey and mauve cells with lined out text.

The only panel to pass both impact and DEL and meet the areal weight target was the Polydamp hydrophobic melamine foam. It also performed best in thermal testing. However, the compressibility of the foam makes it a very poor candidate for surviving actual flight conditions. The Soric did not survive impact testing and in some cases DEL. Thinking back to the impact test results (Table 54), Soric LRC 3 mm passed the impact tests; there was not a lightning strike panel made with this material so it should be carried forward.

Five of the six other panels to pass both tests were 3 pcf metallic honeycomb ¼” thick with Innegra S in four cases and Tegris LM in the fifth case, with various lightning strike protection materials, and with

Integument film. The sixth panel was 10 pcf Polyurethane core ¼" thick with Innegra, LDS 50-01 LSP, and Aptiv PEEK film.

The ¼" thick 3 pcf metallic honeycomb is an interesting material. As seen in Table 73, all but one of the panels passed lightning strike tests. The panels are at the upper range of the desired areal weight boundary. Table 74 shows the impact performance of the 3 pcf honeycomb. Both panels passed the necessary 0.5" 50 in-lbs condition and all 1.0" and 1.75" conditions. This would imply there is potentially some excess ability to absorb impact successfully and leads to a question if the metallic honeycomb could be thinner? The downsides of the metallic honeycomb are that it didn't do well in thermal tests and required adhesive on the interface to prevent the core from showing through and to keep the honeycomb cells from filling with resin. The adhesive adds weight, but honeycomb cells full of resin would add even more weight.

Table 72 - Lighting Strike/Impact Combined Results

Panel ID	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film	psf
LS-45	Polydamp Hyrdrophobic Melamine with	None	None	None	None	none	none	0.220
LS-32	Soric XF, 2 mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.354
LS-33	Soric XF, 2 mm thick	Aeropoxy	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.381
~~LS-36~~	~~Soric XF, 2 mm thick~~	~~Aeropoxy~~	~~Tegris LM~~	~~None~~	~~Integument with integrated LSP & PSA~~	~~none~~	~~none~~	~~0.381~~
LS-29	Soric XF, 2 mm thick	Aeropoxy	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.387
~~LS-30~~	~~Soric XF, 2 mm thick~~	~~Aeropoxy~~	~~Innegra S~~	~~Aeropoxy~~	~~0.029 expanded copper foil~~	~~none~~	~~Integument film w/PSA~~	~~0.387~~
LS-37	Soric XF, 6 mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.393
LS-39	Soric LRC, 2 mm thick	Aeropoxy	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.399
~~LS-40~~	~~Soric LRC, 2 mm thick~~	~~Aeropoxy~~	~~Innegra S~~	~~None~~	~~Integument with integrated LSP & PSA~~	~~none~~	~~none~~	~~0.408~~
~~LS-38~~	~~Soric XF, 6 mm thick~~	~~Aeropoxy~~	~~Innegra S~~	~~None~~	~~Integument with integrated LSP & PSA~~	~~none~~	~~none~~	~~0.423~~
LS-34	Soric XF, 2 mm thick	Aeropoxy	Innegra S	None	LORD Spray Material	none	Integument film w/PSA	0.440
LS-35	Soric XF, 2 mm thick	Aeropoxy	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none	0.446
LS-22	3 pcf metallic honeycomb, 1/4" thck	Grade 30 adhesive	Tegris LM	None	Integument with integrated LSP & PSA	none	none	0.464
LS-18	3 pcf metallic honeycomb, 1/4" thck	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.470
LS-15	3 pcf metallic honeycomb, 1/4" thck	Grade 30 adhesive	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.488
LS-42	10 pcf PU core, 1/4" thick	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	adhesive	Aptiv PEEK Film w/PSA	0.488
LS-16	3 pcf metallic honeycomb, 1/4" thck	Grade 30 adhesive	Innegra S	Aeropoxy	0.029 expanded copper foil	none	Integument film w/PSA	0.494
~~LS-44~~	~~10 pcf PU core, 1/4" thick~~	~~Aeropoxy~~	~~Innegra S~~	~~Aeropoxy~~	~~LDS 50-01 0.007 psf aluminum~~	~~adhesive~~	~~Kapton film~~	~~0.494~~
LS-19	3 pcf metallic honeycomb, 1/4" thck	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.500

Key

~~Text~~	Failed Lightning Strike (LS)
	Failed Impact
~~Te xt~~	Failed both LS and Impact

Table 73 - 1/4" Thick 3 pcf Metallic Honeycomb Lightning Strike Performance

Panel ID	Impact Absorbing Foam Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike Material	Interface	Aesthetic Film	psf
LS-22	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Tegris LM	None	Integument with integrated LSP & PSA	none	none	0.464
LS-18	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra S	Aeropoxy	LDS 50-01 0.007 psf aluminum	none	Integument film w/PSA	0.470
LS-15	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra S	Aeropoxy	0.016 psf expanded aluminum foil	none	Integument film w/PSA	0.488
LS-16	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra S	Aeropoxy	0.029 expanded copper foil	none	Integument film w/PSA	0.494
LS-19	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.500
~~LS-20~~	~~3 pcf metallic honeycomb, 1/4" thick~~	~~Grade 30 adhesive~~	~~Innegra S~~	~~None~~	~~LORD Spray Material~~	~~none~~	~~Integument film w/PSA~~	~~0.530~~
LS-21	3 pcf metallic honeycomb, 1/4" thick	Grade 30 adhesive	Carbon Epoxy	None	Integument with integrated LSP & PSA	none	none	0.548
LS-24	3 pcf metallic honeycomb, 3/4" thick	Grade 30 adhesive	Innegra S	None	Integument with integrated LSP & PSA	none	none	0.625

Table 74 - 1/4" Thick 3 pcf Metallic Honeycomb Impact Performance

				.5" Impacter			1.0" Impacter			1.75" Impacter			
Panel	Absorbing Layer	Spreading Layer	psf	50	180	250	50	180	250	50	180	250	Average
IM-1	None	None	0.000	3	4	4	2	4	4	2	4	4	3.444
IM-100	PHM w/PEEK (3/4" T)	None	0.229	0	4	N/A	0	0	4	0	0	0	1.333
IM-94	Soric XF, 2mm T	Innegra	0.296	0	4	4	0	4	4	0	0	0	1.778
IM-92	Soric LRC, 3mm T	Tegris LM	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-90	Soric LRC, 3mm T	Innegra	0.310	0	4	4	0	0	4	0	0	0	1.333
IM-88	Soric LRC, 2mm T	Tegris LM	0.311	0	4	4	0	4	4	0	0	0	1.778
IM-87	Soric LRC, 2mm T	Innegra	0.328	0	4	4	0	3	4	0	3	3	2.333
IM-95	Soric XF, 2mm T	Tegris LM	0.328	0	4	4	0	3	4	0	3	4	2.444
IM-97	Soric XF, 6mm T	Innegra	0.351	0	4	4	0	3	4	0	0	0	1.667
IM-99	Soric XF, 6mm T	Tegris LM	0.366	0	4	4	0	1	3	0	0	0	1.333
IM-93	Soric XF, 2mm T	Carbon epoxy	0.373	0	4	4	0	0	4	0	0	0	1.333
IM-89	Soric LRC, 3mm T	Carbon epoxy	0.391	0	4	4	0	0	4	0	0	0	1.333
IM-86	Soric LRC, 2mm T	Carbon epoxy	0.395	0	3	4	0	0	4	0	0	0	1.222
IM-47	3 pcf Al H/C, 1/4" T	Tegris LM	0.409	0	4	4	0	0	0	0	0	0	0.889
IM-45	3 pcf Al H/C, 1/4" T	Innegra	0.411	0	4	4	0	0	0	0	0	0	0.889
IM-96	Soric XF, 6mm T	Carbon epoxy	0.423	0	4	4	0	0	0	0	0	0	0.889
IM-98	Soric XF, 6mm T	0.012" alum	0.469	0	3	4	0	0	0	0	0	0	0.778
IM-5	10# PU core, 1/4" T	Tegris LM	0.473	0	4	4	0	0	0	0	0	0	0.889
IM-3	10# PU core, 1/4" T	Innegra	0.475	0	3	4	0	0	0	0	0	0	0.778
IM-61	6 pcf Al H/C, 1/4" T	Tegris LM	0.475	0	4	4	0	0	0	0	0	0	0.889
IM-44	3 pcf Al H/C, 1/4" T	Carbon epoxy	0.488	0	4	4	0	0	0	0	0	0	0.889
IM-59	6 pcf Al H/C, 1/4" T	Innegra	0.490	0	2	4	0	0	3	0	0	0	1.000
IM-49	3 pcf Al H/C, 1/2" T	Innegra	0.490	0	4	4	0	0	0	0	0	0	0.889

7.5.2 Initial Thoughts on Final Material Selection

The analysis of the test data for the first-generation protective skins suggests the following materials as good candidates for the final set of STAR-C2 protective skins:

- Polydamp hydrophobic melamine with metalized PEEK skin with a layer of Innegra, LSP, and film
- Soric LRC 3 mm, 3 pcf metallic core (perhaps less than ¼" thick), and 10 pcf polyurethane core (again perhaps less than ¼" thick) for the impact absorbing materials
- Innegra (similar results to Tegris but easier to work with) and carbon epoxy (too heavy but excellent results) for impact spreading materials
- LDS 50-01 0.007 psf aluminum for lightning strike protection (it gave good results and was very light)
- Integument with PSA and 3M 5004 with PSA with opaque same color for aesthetic film

The actual determination of the test panel matrix for the final set of STAR-C^2 protective skins was made in the next phase of this research program.

8 Second-Generation Test Articles

Using lessons learned from the first generation of test articles, a second (and final for this effort) generation of test articles was defined. Similar to the first generation of test articles, the second generation was tested for impact, electromagnetic effects, aesthetics and smoothing, and thermal. In addition, acoustic testing was done to see how effective the STAR-C^2 test articles were at absorbing acoustic energy. Section 8 will describe the test articles, the manufacturing challenges and lessons learned, and the test results.

8.1 Test Article Definitions

8.1.1 Material Definition

The materials used to perform the impact and acoustic energy absorption function are shown in Table 75. These materials are, except for the Polydamp hydrophobic melamine, identical to the materials used in the first-generation test panels. The Polydamp hydrophobic melamine had pressure sensitive adhesive on both sides of the foam for the second-generation skin. Replacing the metalized peek skin with Innegra and LDS 50-01 provided both an impact spreading layer and lightning protection.

Table 75 - Impact Materials for Second-Generation Protective Skins

Material Trade Name	Material Composition
10 pcf polyurethane core, FR-6710	Polyurethane
3 pcf metallic honeycomb core (1/4" cell, 5052 aluminum, 0.0015" thick wall, nominally 3.1 pcf/ft^3)	Aluminum honeycomb
Soric LRC – Low Resin Content (3 mm)	Polyester nonwoven with compression resistant hexagonal cell structure containing synthetic micro-spheres
Polydamp hydrophobic melamine with pressure sensitive adhesive on both sides	Melamine foam

The impact spreading materials used for the second-generation protective skins are shown in Table 76. The Innegra S plain weave fabric was identical to that used for the first-generation skins. The carbon fiber plain weave fabric was also the same fabric, but this time it included aluminum wire woven in the fabric to provide lightning protection (see Figure 105).

Table 76 - Impact Spreading Materials for Second-Generation Protective Skins

Material Trade Name	Material Composition
Innegra S plain weave fabric	Polypropylene
Standard modulus carbon fiber plain weave fabric	Besfight G30-500 3K tow 8 harness satin weave

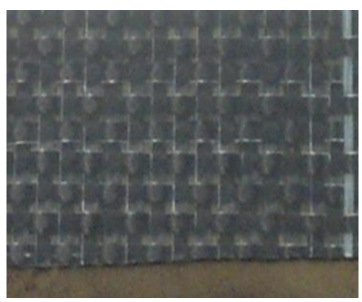


Figure 105: Picture of Carbon ALS (carbon fiber fabric with interwoven aluminum lightning strike protection wire)

Table 77 lists the lightning strike materials used on the second generation of panels. LDS 50-01 was used on the first generation. The ALS system interwoven in the carbon fiber plain weave fabric is new to the project. The goal of this material is to include two functions (impact spreading and lightning strike protection) in one material which can be easily integrated into the protective skin build-up. Previous testing at Cessna of the Carbon ALS fabric has been very successful.

Table 77 - Lightning Strike Protection for Second-Generation Protective Skins

Material Trade Name	Material Composition
LDS 50-01 0.007 psf aluminum	Aluminum
20 gsm nominal interwoven aluminum wire (ALS)	Aluminum wire woven in carbon fiber plain weave fabric

Only one aesthetic layer was used for the second-generation protective skins – Integument – as shown in Table 78. The Integument and 3M 5004 fluoropolymer films were chemically very similar and both provided good results on the first-generation protective skins. One lesson learned from the tests was that effective evaluation of aesthetics requires materials of similar color and transparency. Integument had sufficient quantities of opaque white film to cover all of the second-generation test articles immediately available. The 3M 5004 was not available in opaque white in a timely manner. The Integument film had a shiny side and a matte side. The pressure sensitive adhesive was applied to the matte side so that the shiny side was visible (similar to shiny aircraft paint).

Table 78 - Aesthetic Layer for Second-Generation Protective Skins

Material Trade Name	Material Composition
Integument film with pressure sensitive adhesive	Fluorogrip polymer film (ethylene-chlorotrifluoroethylene)

The interface layers for the second-generation protective skins are shown in Table 79. The 3M 4950 VHB double-sided foam tape and the Grade 30 film adhesive are the same as used for the first-generation skins. The Aeropoxy PR2032 and hardener PH3660 were replaced by Epon Epoxy (9504 Resin and 9554 Hardener). The 3M F9460PC transfer tape was eliminated completely from the second-generation protective skins since it was hard to handle and difficult to make look good.

Table 79 - Interface Layers for Second-Generation Protective Skins

Material Trade Name	Material Composition
3M 4950 Very High Bond (VHB) Double-Sided Foam Tape (45 mil thick)	Viscoelastic acrylic foam
Epon Epoxy (9504 Resin and 9554 Hardener)	Multifunctional acrylate resin and modified amine mixture with diphenylolpropane hardener
Grade 30 film adhesive	FM 73C fracture-tough modified epoxy-nitrile structural film

The materials listed above were combined into the six test articles shown in Table 80. For the second-generation test articles, all test articles were complete protective skins (i.e., had all layers of materials).

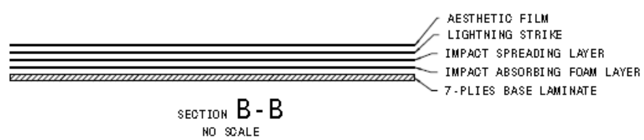
Table 80 - Second-Generation Test Article Definition

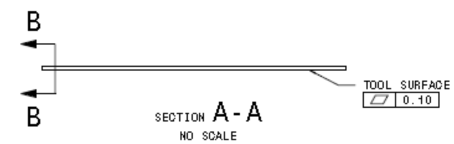
Panel pcf	Interface	Impact Absorbing	Interface	Impact Spreading	Interface	Lightning Strike	Aesthetic Film
FXX-1	3M 4950	3 mm Soric LRC	Epon Epoxy	Innegra	Epon Epoxy	LDS 50-01	Integument Film with PSA
FXX-2	3M 4950	3 mm Soric LRC	Epon Epoxy	Carbon ALS	None	None	Integument Film with PSA
FXX-3	3M 4950	¼" 3 pcf metallic honeycomb	Grade 30 Adhesive	Innegra	Epon Epoxy	LDS 50-01	Integument Film with PSA
FXX-4	3M 4950	¼" 10 pcf PU Core	Epon Epoxy	Innegra	Epon Epoxy	LDS 50-01	Integument Film with PSA
FXX-5	3M 4950	¼" 10 pcf PU Core	Epon Epoxy	Carbon ALS	None	None	Integument Film with PSA
FXX-6	PSA	Polydamp (1/2")	PSA	Innegra	Epon Epoxy	LDS 50-01	Integument Film with PSA

8.1.2 Drawings

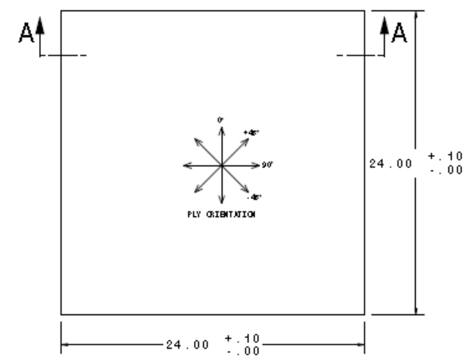
The drawing for the second-generation impact and aesthetics and smoothing test articles is shown in Figure 106. Like the first-generation panels, these are 24 inches x 24 inches. This time both sets of panels have the impact absorbing, impact spreading, lightning strike, and aesthetic film on all panels. The acoustics test articles (shown in Figure 107) are identical to the second-generation impact and aesthetics and smoothing test articles except for size – the acoustics test articles are 48 inches x 48 inches for compatibility with acoustic test facilities.

The lightning strike test articles are shown in Figure 108. Like the first-generation articles, the impact absorbing/spreading layers are inset one inch from the panel edge so that the panels will fit in the transmissivity chamber. The aesthetic film is inset another 0.75 inches from the edges of the impact layers to leave room for grounding in the "L" frame (which was shown in Figure 71).





PANEL ID	INTERFACE	IMPACT ABSORBING LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	LIGHTNING STRIKE	AESTHETIC FILM
FAS/FIM-1	3M 4950	3 mm Soric LRC	CSAC006 TYPE 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAS/FIM-2	3M 4950	3 mm Soric LRC	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FAS/FIM-3	3M 4950	1/4" 3# Metallic Honeycomb	Grade 30 Adhesive	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAS/FIM-4	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAS/FIM-5	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Carbon ALS	NONE	None	Integument Film with PSA
FAS/FIM-6	None	Polydamp (1/2")	None	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA



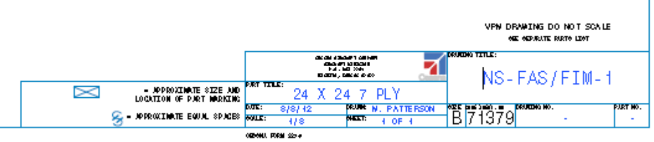
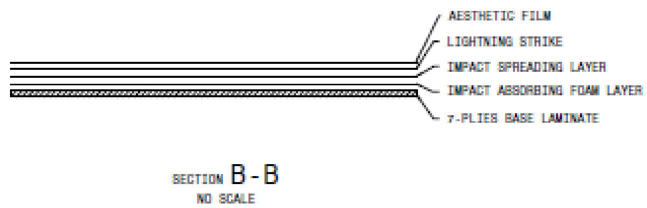
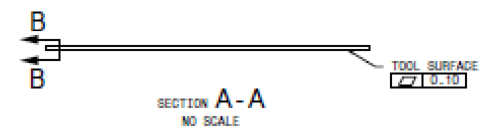
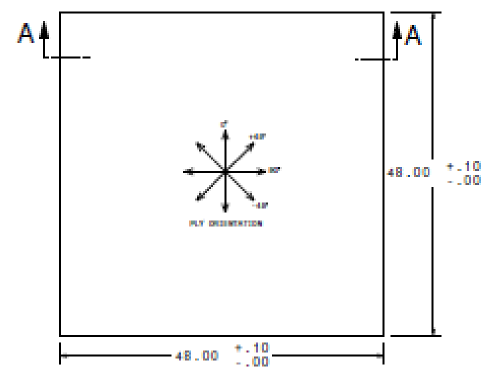


Figure 106: Second-generation impact and aesthetics & smoothing test article drawing.







PANEL ID	INTERFACE	IMPACT ABSORBING LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	LIGHTNING STRIKE	AESTHETIC FILM
FAC-0	None	None	None	None	None	None	None
FAC-1	3M 4950	3 mm Soric LRC	CSAC006 TYPE 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-2	3M 4950	3 mm Soric LRC	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FAC-3	3M 4950	1/4" 3# Metallic Honeycomb	Grade 30 Adhesive	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-4	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-5	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Carbon ALS	NONE	None	Integument Film with PSA
FAC-6	None	Polydamp (1/2")	None	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA

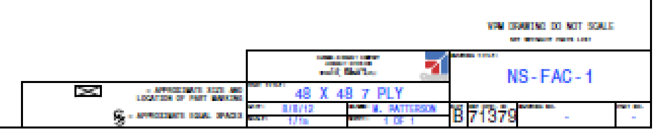
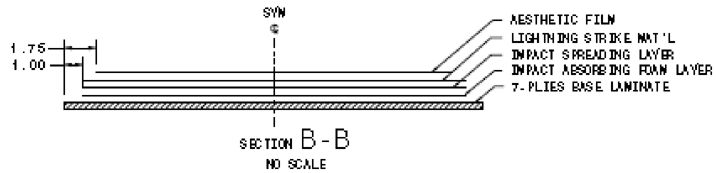
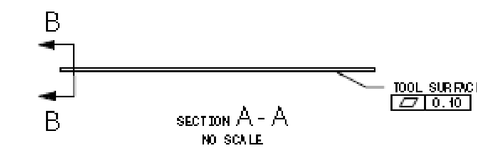
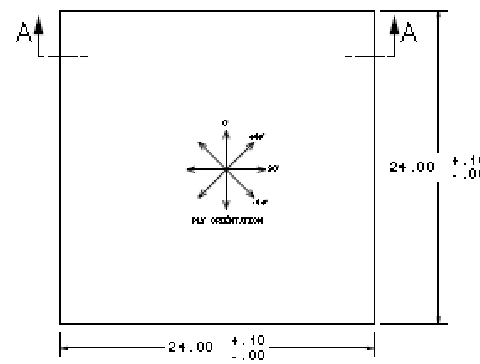


Figure 107: Acoustics test article drawing (only second generation).





PANEL ID	INTERFACE	IMPACT ABSORBING LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	LIGHTNING STRIKE	AESTHETIC FILM
FLS-1	3M #950	3 mm Soric LRC	CSAC006 TYPE 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FLS-2	3M #950	3 mm Soric LRC	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FLS-3	3M #950	1/4" 3# Metallic Honeycomb	Grade 30 Adhesive	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FLS-4	3M #950	1/4" 10# PU	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FLS-5	3M #950	1/4" 10# PU	CSAC006 Type 1 Resin	Carbon ALS	NONE	None	Integument Film with PSA
FLS-6	None	Polydamp (1/2")	None	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA



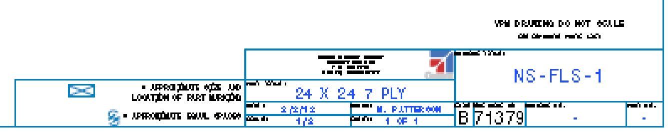
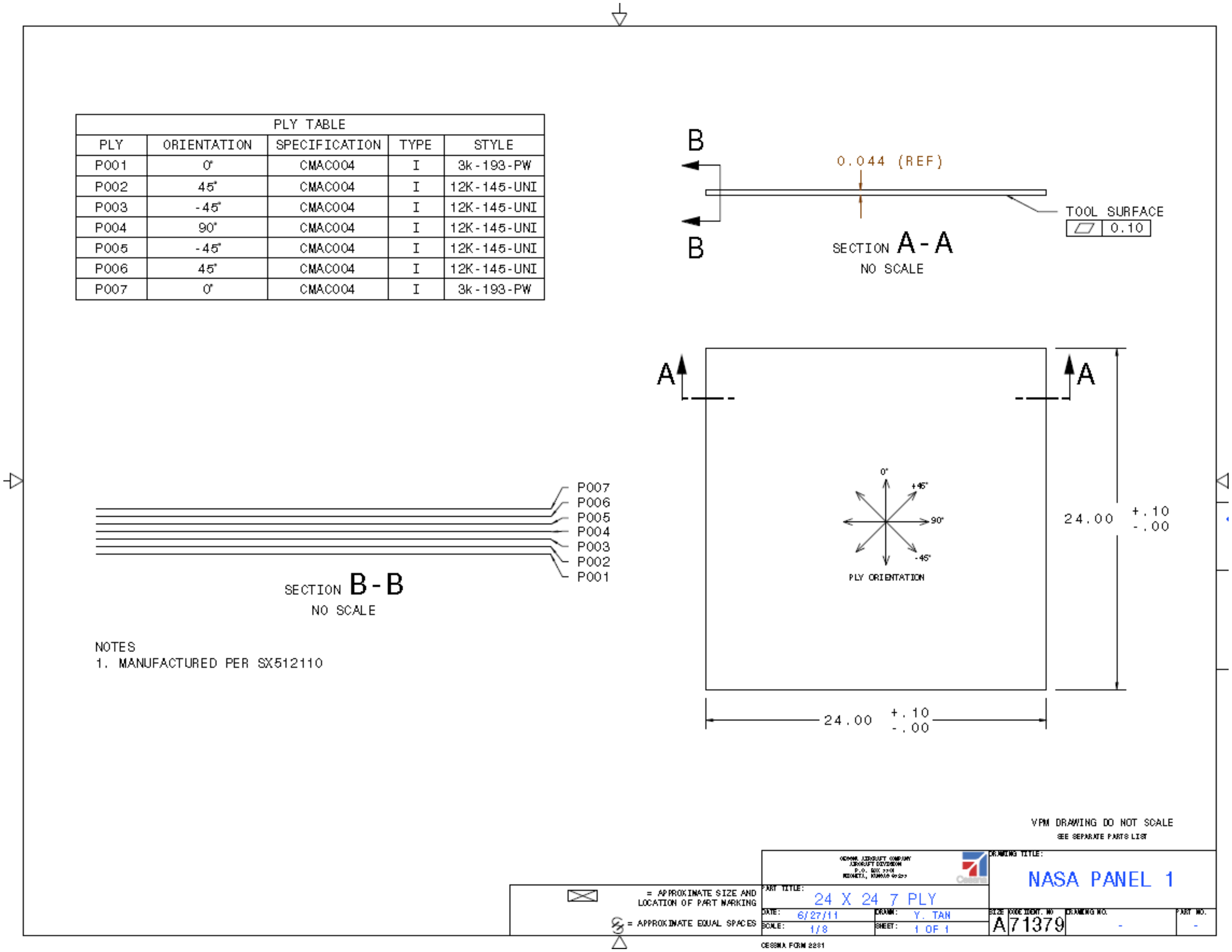


Figure 108: Second-generation lightning strike test article drawing.

The first-generation base substrate laminates were seven plies of carbon uni-directional tape with epoxy to support automated manufacturing which might be appropriate in 2030-2035. As mentioned in Section 7.2.6, when impacted the laminates tended to split in the direction of the outer layers of uni-directional tape. To prevent splitting, the second-generation base panels were constructed with five plies of carbon uni-directional tape and an outer layer of woven material on each side of the panel as shown in Figure 109 for the 24 inch by 24 inch panels. The base substrate panel drawing for the acoustic panels is shown in Figure 110; the only difference between it and the other panels is size (48 inches by 48 inches). The woven material successfully acts as a stop to minimize crack growth (see Figure 111).



PLY TABLE				
PLY	ORIENTATION	SPECIFICATION	TYPE	STYLE
P001	0°	CMAC004	I	3k-193-PW
P002	45°	CMAC004	I	12K-145-UNI
P003	-45°	CMAC004	I	12K-145-UNI
P004	90°	CMAC004	I	12K-145-UNI
P005	-45°	CMAC004	I	12K-145-UNI
P006	45°	CMAC004	I	12K-145-UNI
P007	0°	CMAC004	I	3k-193-PW

Figure 109: Second-generation base substrate laminate drawing.

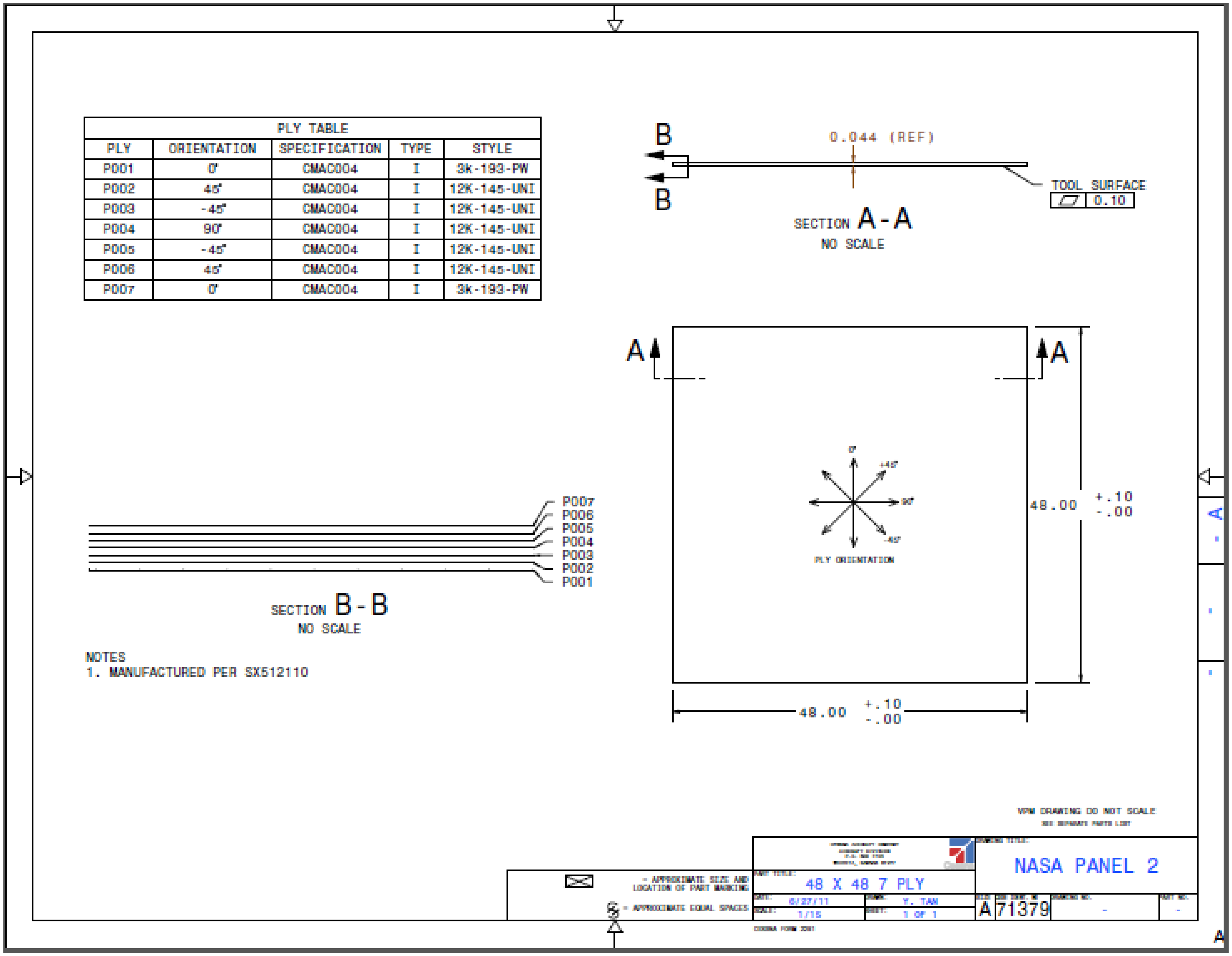


Figure 110: Acoustics base substrate panel drawing.

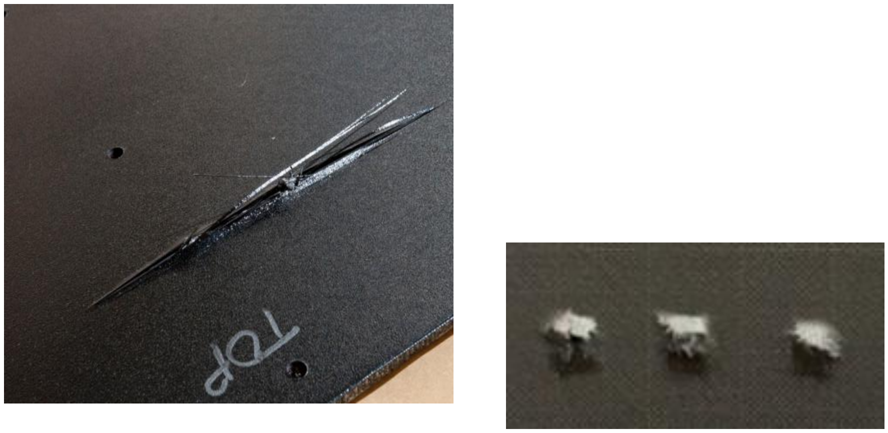


Figure 111: Base substrate panel impact effect for uni-directional (left) and plain weave (right) outer layer.

8.1.3 *Manufacturability*

This was the second time through working with these materials but the supplier building the panels changed and different manufacturing methods were used, so there were still lessons learned from building the protective skins.

The steps to manufacture the panels are shown on the left side of Figure 112 for the panels made with Soric or Polyurethane core and Innegra (FXX-1 and FXX-4). The right side of Figure 112 shows the steps to manufacture the panels made with Soric or Polyurethane core and Carbon ALS (FXX-2 and FXX-5). (The FXX designation is used because the panels could be FIM or impact, FLS or lightning strike, FAS or aesthetics & smoothing, and FAC or acoustic. The same processes were used to make all of the panels.) The process steps for the Soric and Innegra are identical except for the extra step of adding the layer of LDS 50-01 for the Innegra panels; Carbon ALS has the lightning protection already included in the material.

The left side of Figure 113 shows the process of manufacturing the panel with metallic honeycomb while the right side of the figure shows the process of manufacturing the panel with the Polydamp Hydrophobic Melamine. The process to combine Innegra and LDS 50-01 is identical. The metallic honeycomb requires the addition of adhesive (which adds weight) to keep the resin from filling the honeycomb and adding a lot of weight during the second VARTM process. Applying the Integument film to the LDS 50-01 is the same for both articles. The metallic honeycomb uses the double-sided tape to attach the honeycomb to the base substrate panel. The Polydamp Hydrophobic Melamine has pressure sensitive adhesive on both sides so does not require the double-sided tape, reducing weight but perhaps also reducing the amount of impact resistance.

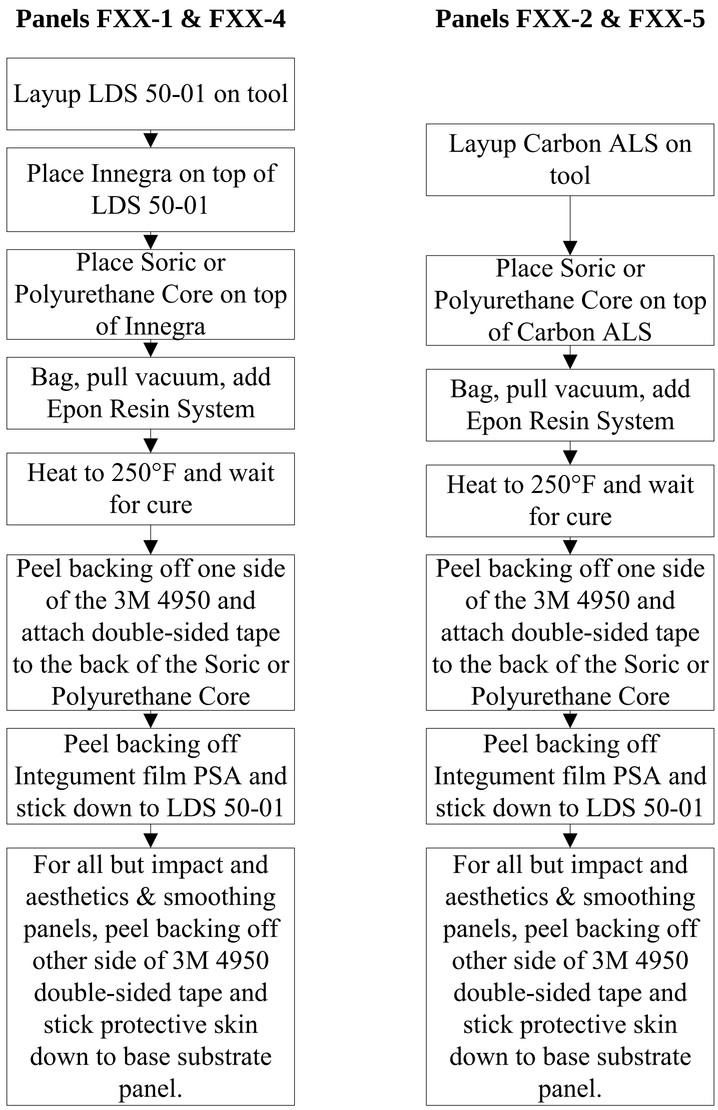


Figure 112: Manufacturing Process Steps for Innegra (left) and Carbon ALS (right) panels.

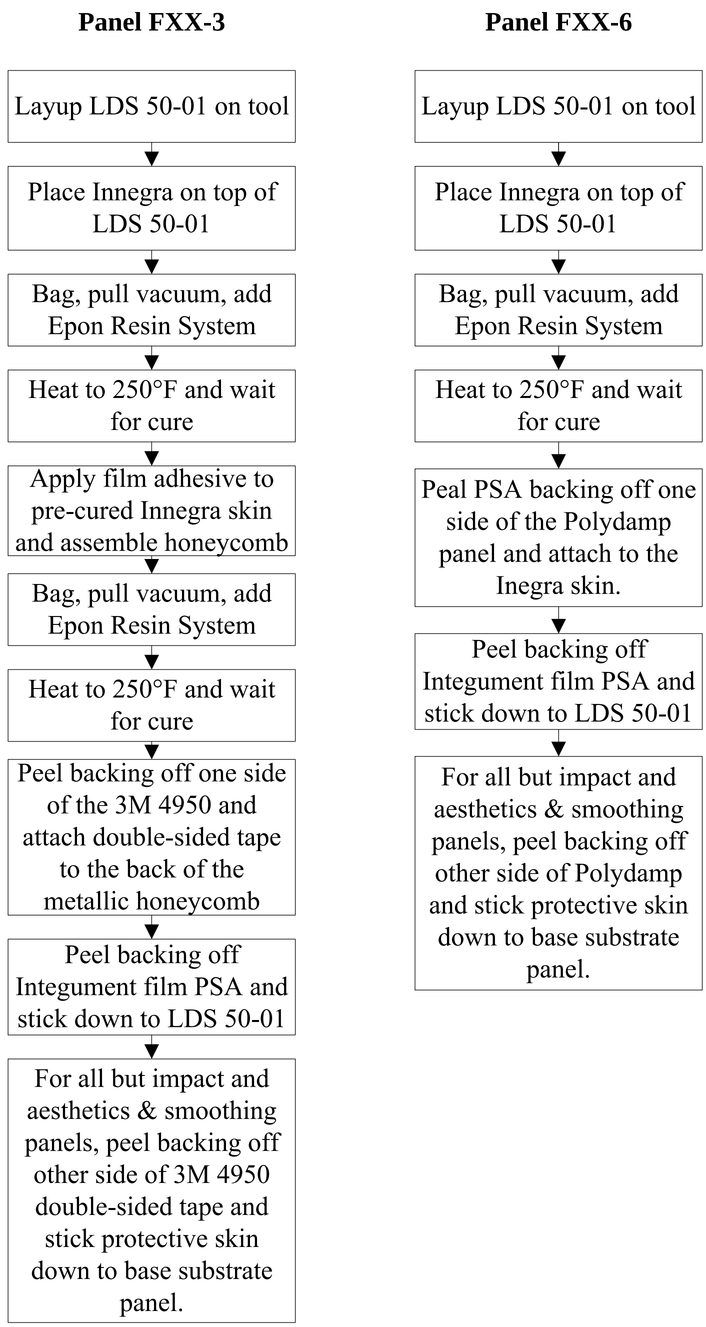


Figure 113: Manufacturing process steps for metallic core panel (left) and Polydamp panel (right).

There were three main challenges in the manufacturing process: 1) protective skin warpage during cure for the Soric and Polyurethane Core panels; 2) LDS 50-01 manufacturing flaws and fragility; and 3) difficulty putting down the Integument film smoothly and without bubbles or wrinkles. Each of these challenges will be described in the following subsections.

8.1.3.1 *Protective Skin Warpage during Cure*

The protective skin original cure temperature was 250°F. Protective skins FXX-2 and FXX-5 (Soric with carbon ALS and polyurethane core with carbon ALS) – all of the panels with carbon ALS – warped badly during the cure process (see Figure 114 and Figure 115). The warpage was bad enough that the protective skins broke during trying to flatten them out to attach to the base substrate panels.

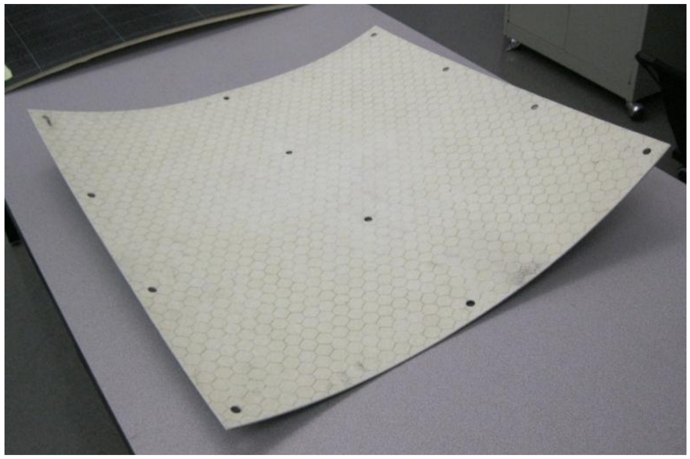


Figure 114: Post manufacturing warpage of protective skin FIM-2.

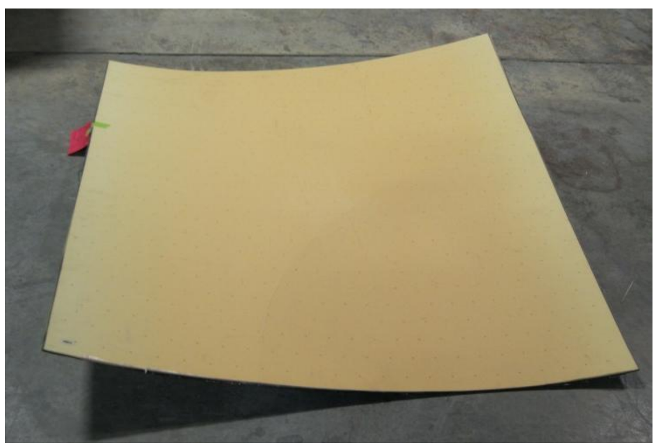


Figure 115: Post manufacturing warpage of protective skin FAC-5.

The warpage happened in the first four steps of the process for FXX-2 and FXX-5; it did not happen in the same equivalent five steps for FXX-1 and FXX-4. All of the materials were the same, including the resin system for the VARTM process, except Innegra and LDS 50-01 versus Carbon ALS. The panels made with Carbon ALS are the ones that warped. Both Innegra and carbon fibers have negative coefficients of thermal expansion by themselves (refs. 17 and 18, respectively). Aluminum has a positive coefficient of thermal expansion (ref. 19). Perhaps the expansion of the greater surface area of the LDS 50-01 in contact with the Innegra and resin helped offset the shrinkage of the Innegra, causing less warpage than the carbon with only a small amount of aluminum wires in contact with the carbon and resin.

Reducing the cure temperature to 125°F, while extending the cure time, reduced the warpage to a workable level. Even better would be a resin that develops full strength characteristics with a room temperature cure.

8.1.3.2 ***LDS-50 Fragile Material***

The LDS 50-01 material from Lightning Diversion Systems is extremely fragile. Supplied in 24 inch by 26 inch sheets, almost every sheet contains some flaw. A few of the flaws were large enough to require scrapping the sheet. The fragility and flaws were frustrating for protective skin manufacturing, but did not seem to harm the lightning strike protection performance. The manufacturer noted that the material is handled in the plant and then sent to an outside company for further processing. That leads to some flaw(s) in the material. Scaling up to sizes more representative of full-scale aircraft could be a challenge.

8.1.3.3 ***Integument Film Bubbles and Wrinkles***

The manufacturer of the second-generation protective skins had a very difficult time getting the Integument film down without bubbles and/or wrinkles in the film. The problem was especially bad for the larger acoustic test articles. Integument was contacted and provided a set of work instructions along with some advice on getting the film down wrinkle/bubble free. The techniques being used by the manufacturer were very similar to what Integument recommended. There is certainly some art and a learning curve to success with visually appealing application of the film.

8.1.4 Base Panel Inspection

The second-generation base substrate panels were inspected using the same methods employed for the first-generation panels. Each panel was weighed and measurements. Measurements were made in accordance with Figure 30. The 24” x 24” panel weights and measurements are shown in Table 81 while

Table 82 shows the weights and measurements for the 48” x 48” base substrate panels for the acoustics test articles.

The tables contain some panels with the notation “No OL” next to the panel number. This notation was necessary because many of the panels were made with overlaps (rather than butt splices) where necessary. Even though the material size was large enough to accommodate no overlaps, the panel supplier “helped” by including significant regularly spaced overlaps (see Figure 116 for a visual picture and Figure 117 for a thermographic inspection image). The overlapping material caused added base laminate weight and put obstructions in the testing area of interest. There was some porosity in the overlaps as can be seen in Appendix J – Second-Generation Thermography Report. These panels with overlaps were used for the lightning strike (the target for the direct strike testing was aimed for the empty space between the legs of the “X”) and aesthetics and smoothing panels. The impact panels were all panels without overlap. The acoustics panels had both. In order to ensure that there was no impact of the overlap on transmission loss, two panels with the same configuration except for overlap were run. There was no difference.

The tables also contain two panels that have a “red tg” notation by the panel number. The autoclave heating ramp rate for those two panels was less than the specified rate. The panels were both noticeably heavier than the other similar panels. One possible explanation is that the slower heating rate did not flash off the liquid resin as fast, leaving more resin present. These red tg panels were not used for testing.

After accounting for the no overlap panels and the “red tg” panels, the differences in measurements (especially for the 24” x 24” panels) are very small. The differences in weights from panel to panel are also very small with distinct differences between the overlap and no overlap panels.

Table 81 - Second-Generation 24” x 24” Base Substrate Panel Inspection (1 of 2)

	0.01 lbs	0.05 in													
Panel Number	**Bare Panel Weight**	**L1**	**L2**	**L3**	**L4**	**L5**	**Avg**	**Std Dev**	**W1**	**W2**	**W3**	**W4**	**W5**	**Avg**	**Std Dev**
18170	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18169	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18168	1.52	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18163	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18162	1.48	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18161	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18160	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18164	1.48	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18167	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18157	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18166	1.48	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18155	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18189	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18186	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18165	1.49	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18141	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18172	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18158	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18171	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18187	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00

Table 81 - Second-Generation 24” x 24” Base Substrate Panel Inspection (2 of 2)

	0.01 lbs	0.05 in												
Panel Number	**Bare Panel Weight**	**L1**	**L2**	**L3**	**L4**	**L5**	**Avg**	**Std Dev**	**W1**	**W2**	**W3**	**W4**	**W5**	**Avg**	**Std Dev**
18156	1.50	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18188	1.48	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18830(No OL)	1.46	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18829 (No OL)	1.46	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18831(No OL)	1.45	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18154(red tg)	1.70	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18159	1.48	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.00	24.00	0.00
18201(No OL)	1.44														
18200(No OL)	1.44														
18202(No OL)	already attached														
18129(No OL)	1.44														

Table 82 - Second-Generation 48" x 48" Base Substrate Panel Inspection

	0.01 lbs	0.05 in												
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev
18191	5.94	48.05	48.05	48.10	48.05	48.05	48.06	0.02	48.05	48.05	48.05	48.05	48.05	48.05	0.00
18190	5.94	48.05	48.05	48.05	48.05	48.05	48.05	0.00	48.05	48.05	48.05	48.05	48.05	48.05	0.00
18195	5.94	48.00	48.00	48.00	48.00	48.00	48.00	0.00	48.00	48.00	48.00	48.00	48.00	48.00	0.00
18193	5.95	48.05	48.05	48.00	48.00	48.00	48.02	0.02	48.05	48.00	48.00	48.00	48.00	48.01	0.02
18129 (No OL)	5.82	48.00	48.00	48.00	48.00	48.00	48.00	0.00	48.05	48.05	48.00	48.05	48.05	48.04	0.02
18192 (No OL)	5.8	48.05	48.05	48.05	48.05	48.05	48.05	0.00	48.00	48.00	48.00	48.00	48.00	48.00	0.00
18194 (No OL)	5.82	48.05	48.00	48.00	48.00	48.05	48.02	0.02	48.00	48.00	48.00	48.00	48.00	48.00	0.00
18173 (red tg)	6.04	48.00	48.00	48.00	48.00	48.00	48.00	0.00	48.00	48.00	48.00	48.00	48.00	48.00	0.00
19953 (No OL)	5.80														
19554	5.80														

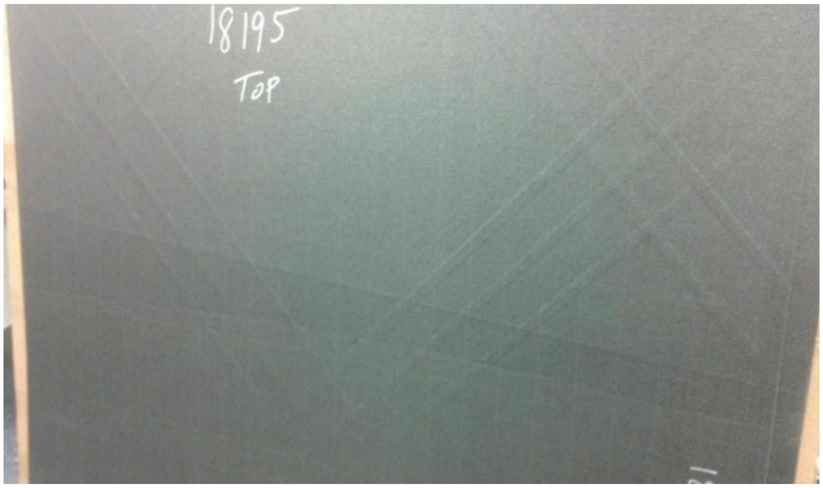


Figure 116: View of back of 48” x 48” base substrate panel with overlap.

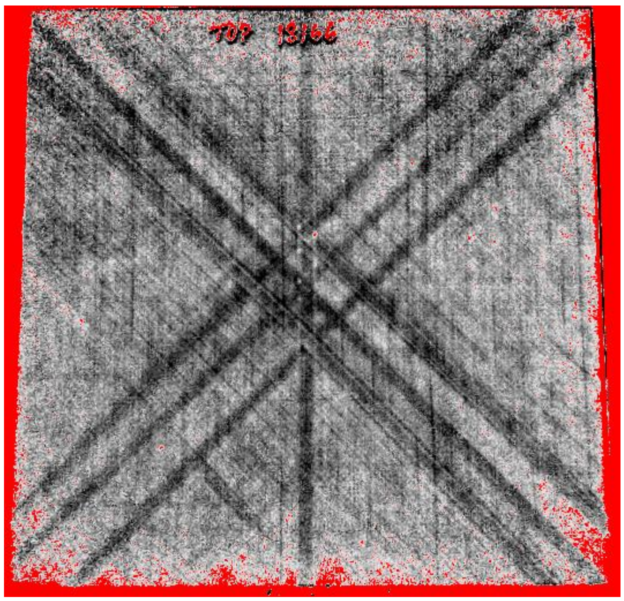


Figure 117: Thermographic view of 24" x 24" base substrate panel with overlap.

8.2 Impact

Impact tests very similar to those conducted on the first generation of protective skins were conducted on the second generation of skins. The impact test fixture designed for the first-generation skins (see Figure 55) was used to conduct impact tests on the second generation of test articles. The test requirements, test objectives, and test results will be described in the following subsections.

8.2.1 Requirements

The primary requirements for impact remain the same (see Table 46). The critical requirement is that the material withstands a 180 in-lb impact with no damage to the base substrate panel. This 180 in-lb energy is obtained by dropping a five pound weight from a height of 36 inches. The other primary

requirement is that the damage which could require repair (Categories 3 and 4 from Reference 2) is visible.

In order to expand the information obtained about the ability of the various materials to withstand impacts, the test matrix consists of three impact energies (150 in-lbs, 180 in-lbs, and 210 in-lbs) with three different impactor diameters (0.5", 1.0", and 1.75") as shown in Table 83. The requirement is 1.0" at 180 in-lbs. The first-generation skins were tested at 50 in-lbs, 180 in-lbs, and 250 in-lbs. Because there was reasonable certainty that these second-generation protective skins would pass the primary requirement, the range of impact energies around that primary requirement was reduced (from 50 to 250 in lbs to 150 to 210 in lbs) to see with how much margin each panel passed.

Table 83 - Second-Generation Skins Impact Test Conditions

Impactor Diameter (in)	0.5	1.0	1.75
Impactor Weight (lbs)	5.0	5.0	5.0
150 in-lbs drop height (in)	30	30	30
180 in-lbs drop height (in)	36	36	36
210 in-lbs drop height (in)	42	42	42
Hail Energy Ref. (in-lbs)	0.83	13.3	124.9

8.2.2 Test Objectives

The test objectives were described in terms of five categories of damage in Section 7.2.4. The goal remains to eliminate categories 3 and 4a damage:

3. Maximum energy to cause hidden damage to the structure below.

4. Maximum energy to cause visible damage to the structure below:

    a. When observed from the back (substrate) side of the test panel.

8.2.3 Test Articles

The second-generation impact test articles were constructed with the materials which were defined in Table 76. The measured and calculated weights of the test article components and the resulting areal density of the test articles are shown in Table 84. In the case of test article FIM-4, the protective skin weight (without backing paper) had to be inferred from the total panel weight and the base substrate panel weight because the protective skins was accidentally attached to the base substrate panel. This also complicated thermographic inspection.

Table 84 - Second-Generation Impact Test Articles Weights and Areal Density

Test Article No.	Panel No.	Protective Skin Weight, lb (with backing paper)	Base Substrate Panel Weight, lb	Total Panel Weight, lb	Areal Density of Protective Skin, lb/ft^2
FIM-0	18129	0	1.44	1.44	0.000
FIM-1	18831	2.58	1.45	4.03	0.645
FIM-2	18829	2.2	1.45	3.65	0.550
FIM-3	18200	1.82	1.44	3.26	0.455
FIM-4*	18202	2.62	1.44	4.06	0.655
FIM-5	18201	2.42	1.44	3.86	0.605
FIM-6	18830	0.98	1.46	2.44	0.245

* Protective skin attached to bare panel before weighing

8.2.4 Test Results

The six second-generation impact panels and one bare substrate panel were tested by applying the nine impacts to each one. Pictures were taken of the front and back of each impact panel before and after impact testing. If features of interest were visible on the impact panel after testing, additional pictures of the features were taken. After impact testing was completed for each panel, thermographic inspection was conducted. The full thermography report is presented in Appendix J. Pictures of the panels before and after impact and thermographic images before and after impact are shown in Figure 118 through Figure 145. For each impact article, four pictures are shown: 1) before and after impact of the front of the panel; 2) before and after impact of the back of the panel; 3) before impact thermographic images; and 4) after impact thermographic images. Images are shown for panel FIM-0 (bare base substrate panel with no protective skin) in Figure 118 through Figure 121. Panel FIM-1 images are shown in Figure 122 through Figure 125. Panel FIM-2 images are shown in Figure 126 through Figure 129. Figure 130 through Figure 133 are the pictures and images from FIM-3. Figure 134 through Figure 137 are the pictures and images from FIM-4. The pictures and images for FIM-5 are shown in Figure 138 through Figure 141. Figure 142 through Figure 145 show the pictures and images from FIM-6.

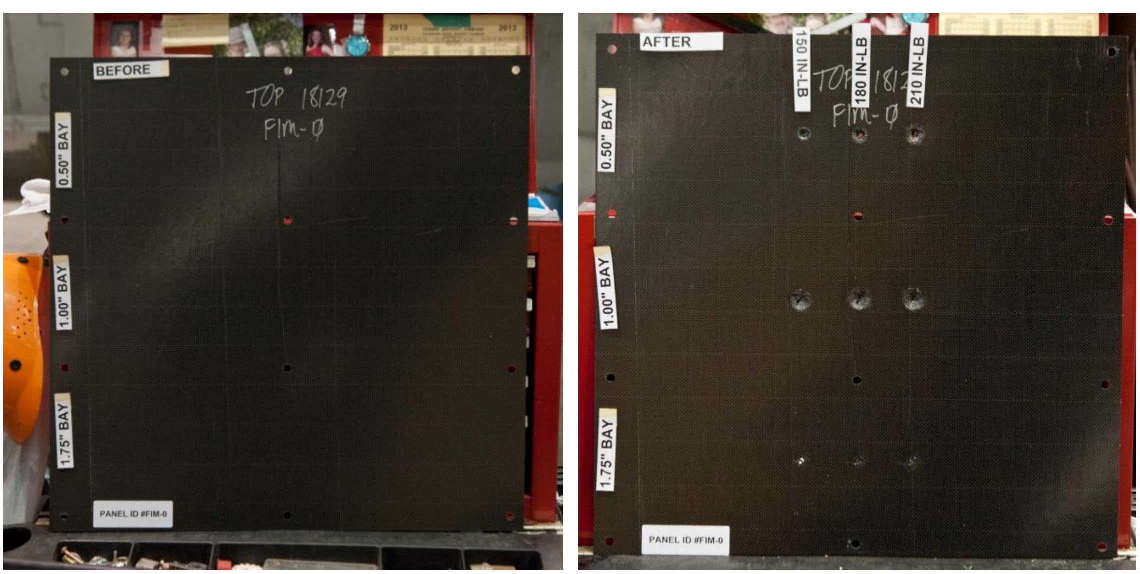
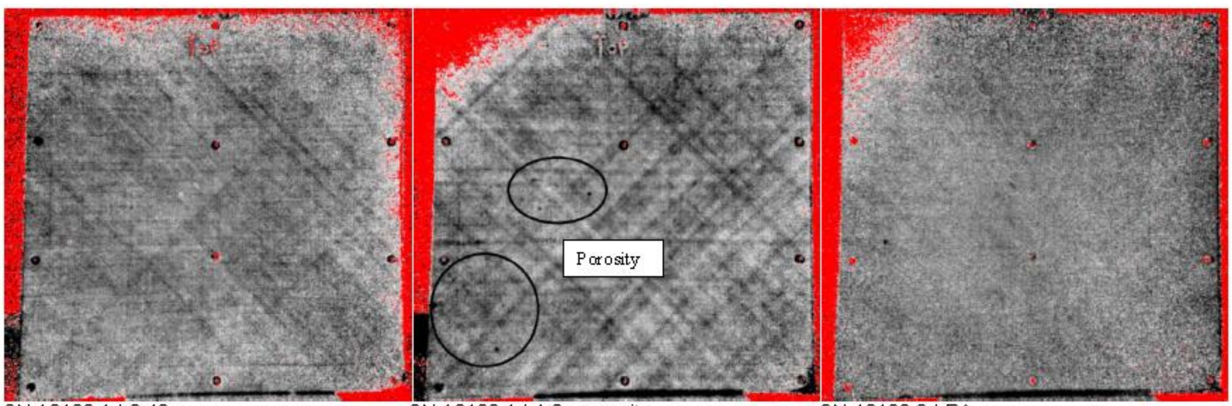


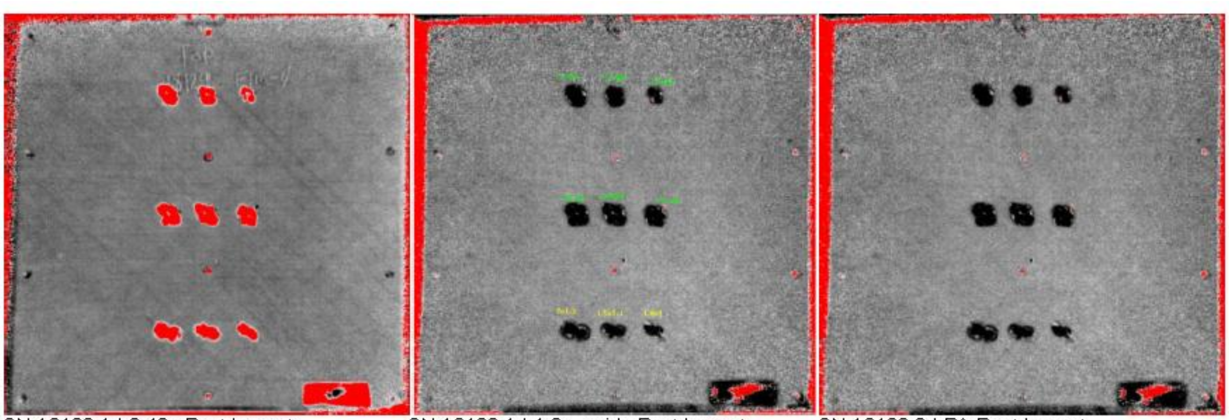
Figure 118: Before and after pictures of the front of FIM-0.

Figure 119: Before and after pictures of the back of FIM-0.



SN 18129 1d 0.42s SN 18129 1d 1.0s porosity SN 18129 2d PA

Figure 120: Before thermographic images of panel FIM-0.



SN 18129 1d 0.42s Post Impact SN 18129 1d 1.0s voids Post Impact SN 18129 2d PA Post Impact

Figure 121: After thermographic images of panel FIM-0.

Figure 122: Before and after pictures of the front of panel FIM-1.

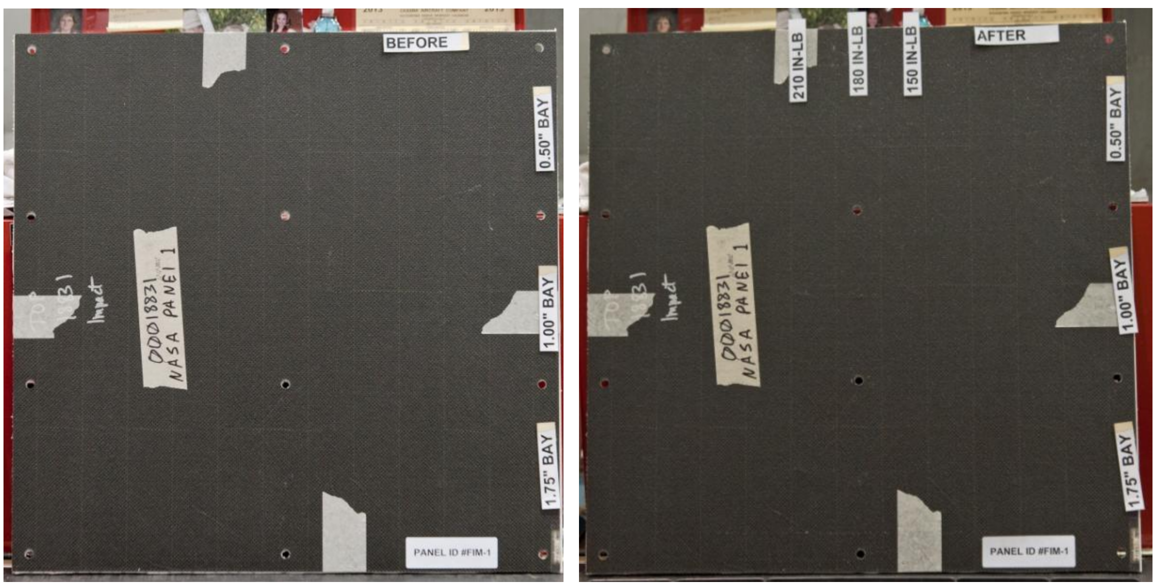


Figure 123: Before and after pictures of the back of panel FIM-1.

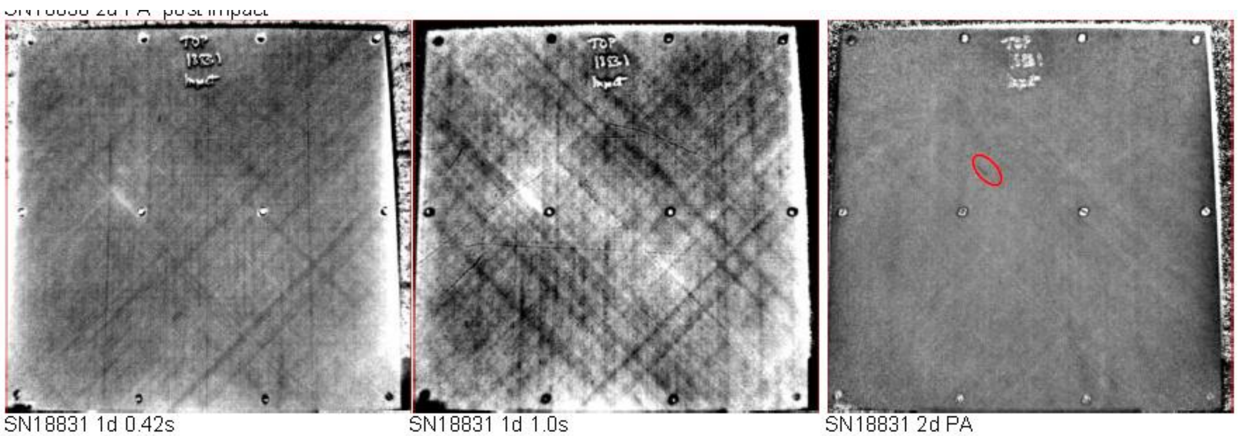


Figure 124: Before thermographic images of panel FIM-1.

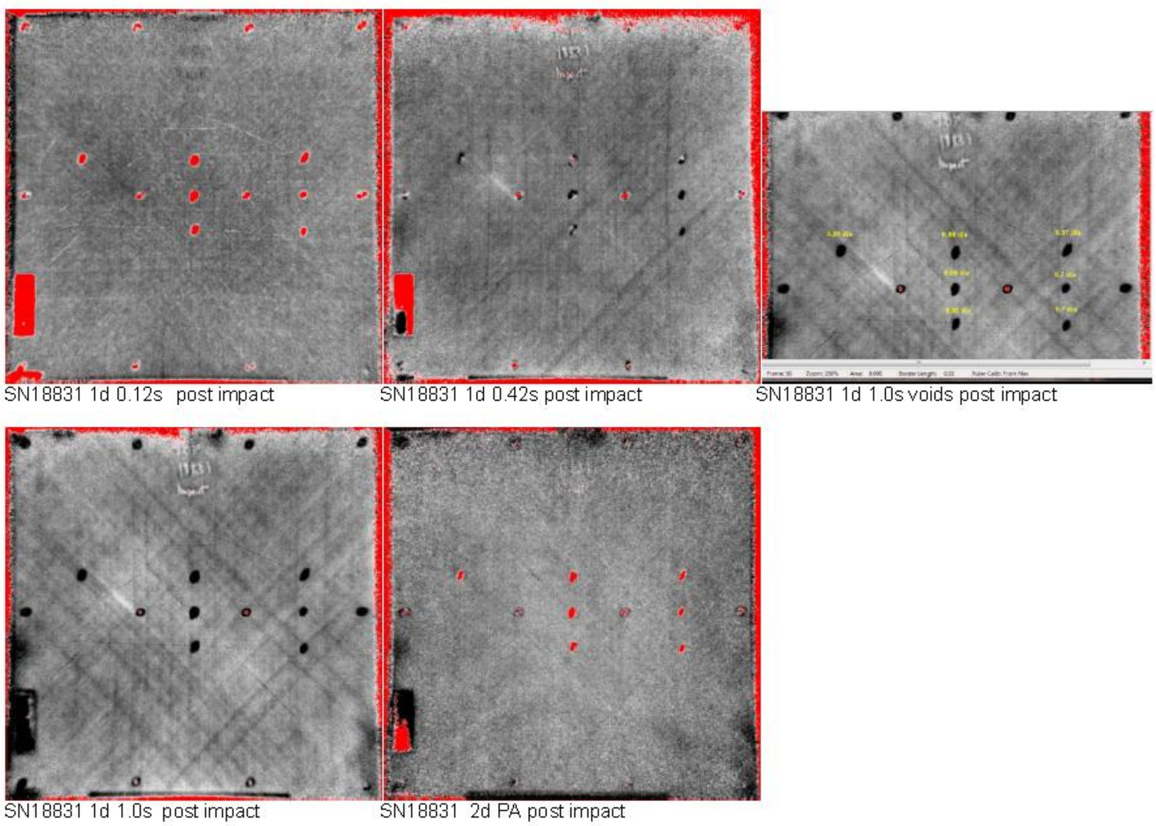


Figure 125: After thermographic images of panel FIM-1.

Figure 126: Before and after pictures of the front of panel FIM-2.

Figure 127: Before and after pictures of the back of panel FIM-2.

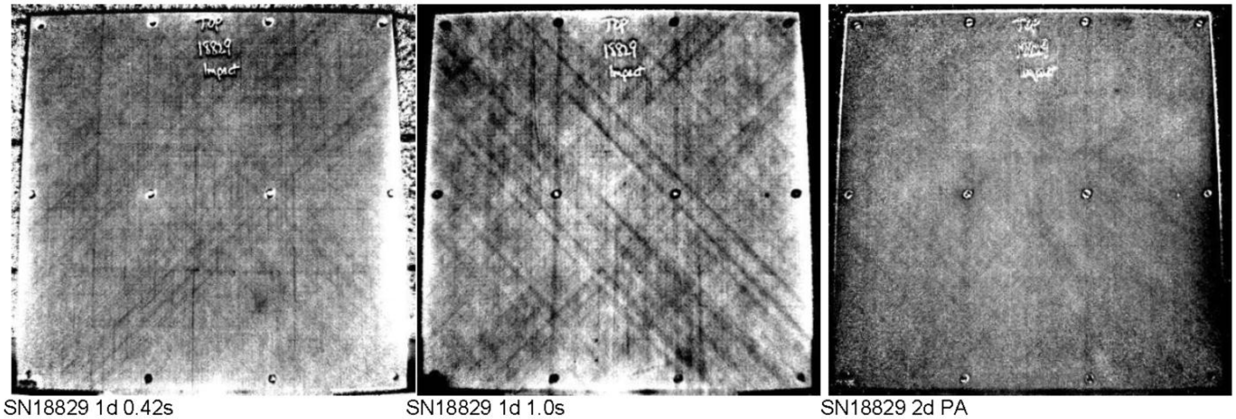


Figure 128: Before thermographic images of panel FIM-2.

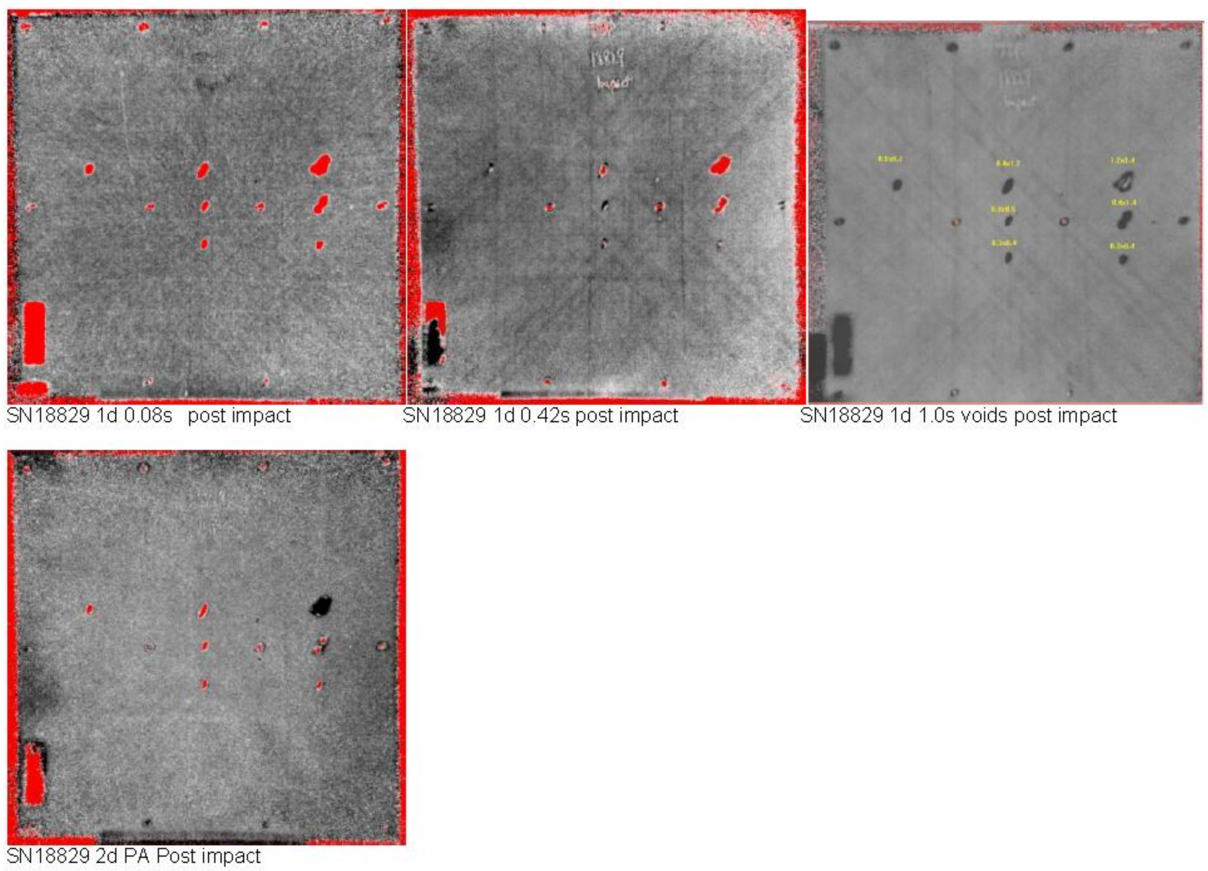


Figure 129: After thermographic images of panel FIM-2.

Figure 130: Before and after pictures of the front of panel FIM-3.

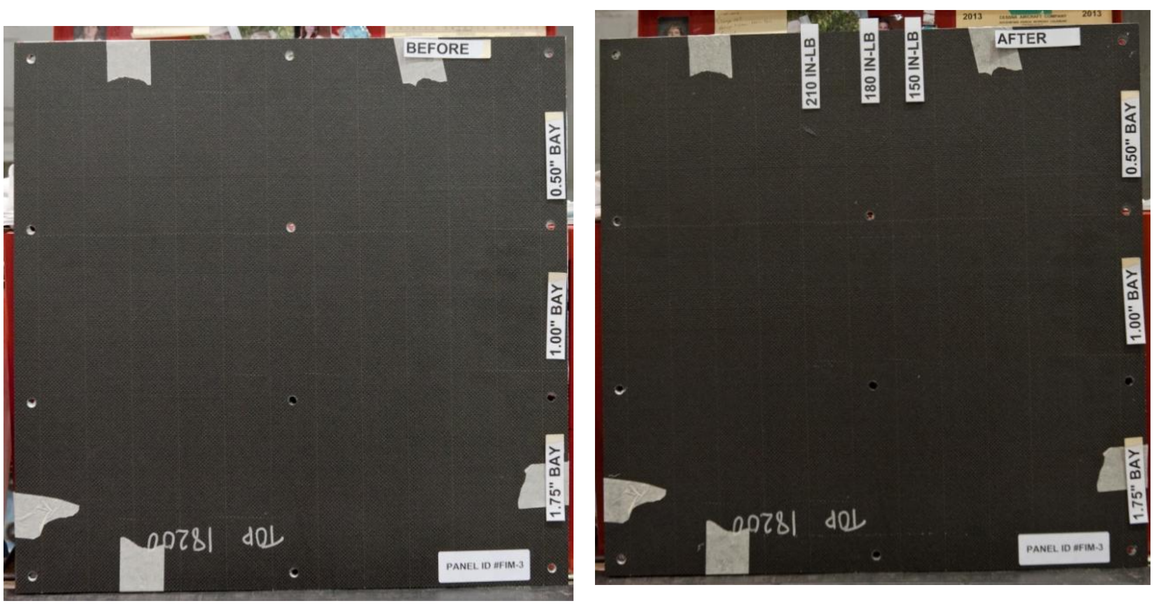


Figure 131 - Before and after pictures of the back of panel FIM-3.

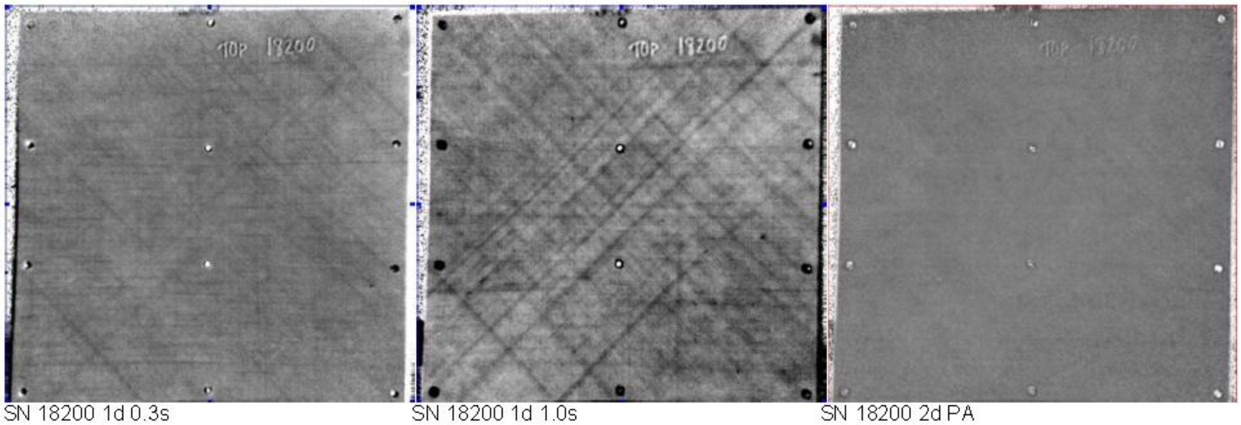


Figure 132: Before thermographic images of FIM-3.

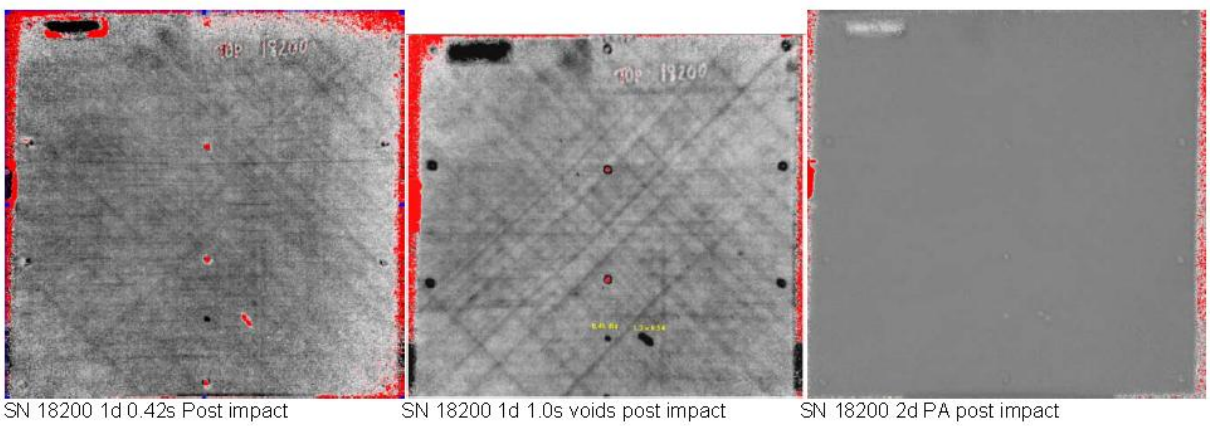


Figure 133: After thermographic image of FIM-3.

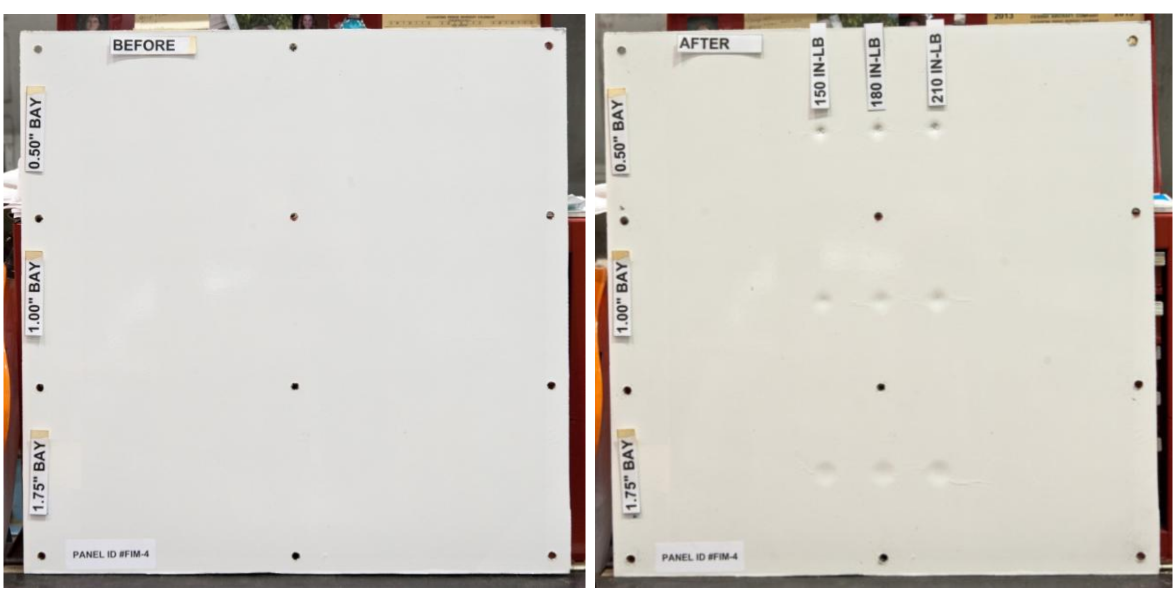
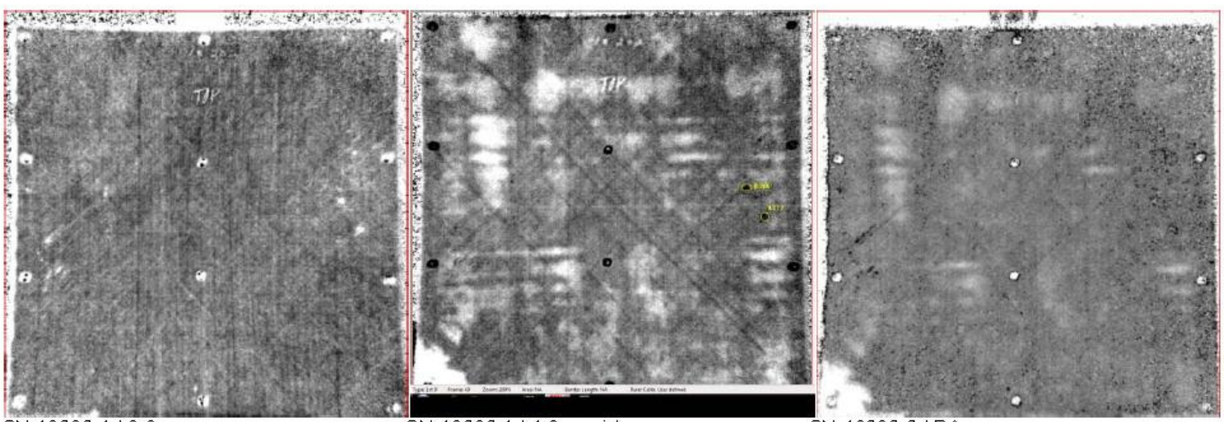


Figure 134: Before and after pictures of front of panel FIM-4.

Figure 135: Before and after pictures of back of panel FIM-4.



SN 18202 1d 0.3s SN 18202 1d 1.0s voids SN 18202 2d PA

Figure 136: Before thermographic images of panel FIM-4.

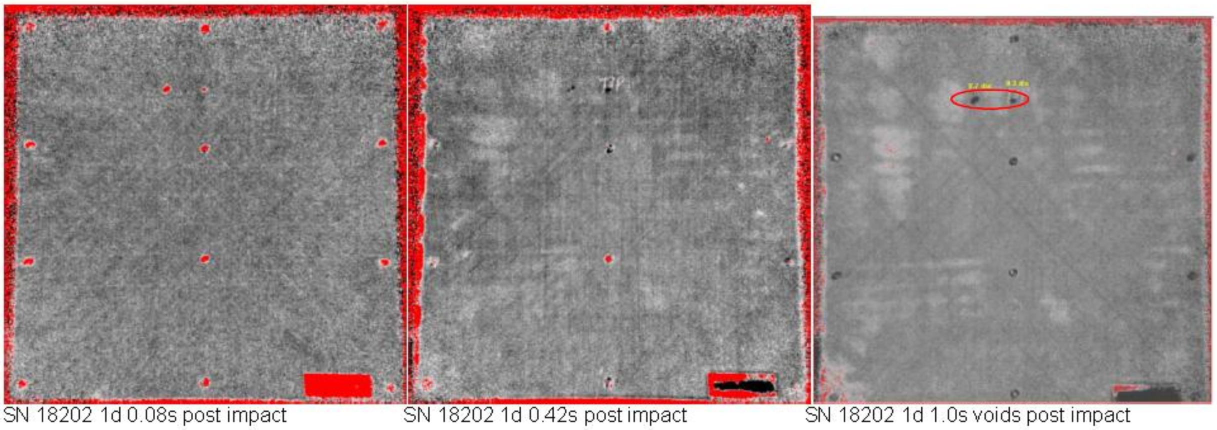


Figure 137: After thermographic images of panel FIM-4.

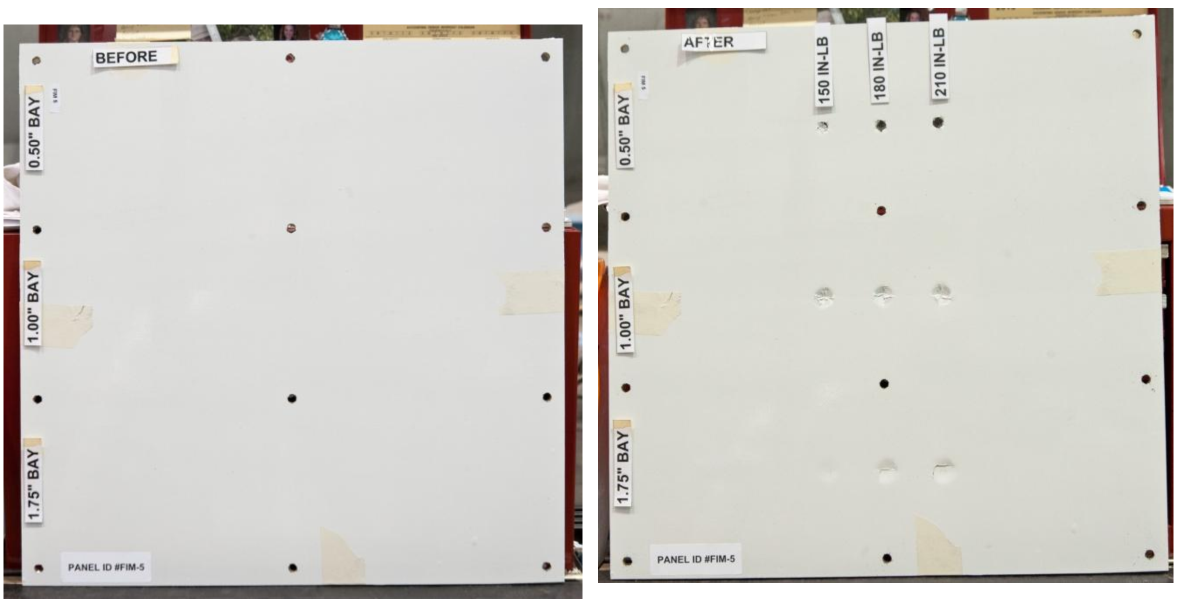


Figure 138: Before and after pictures of front of panel FIM-5.

Figure 139: Before and after pictures of back of panel FIM-5.

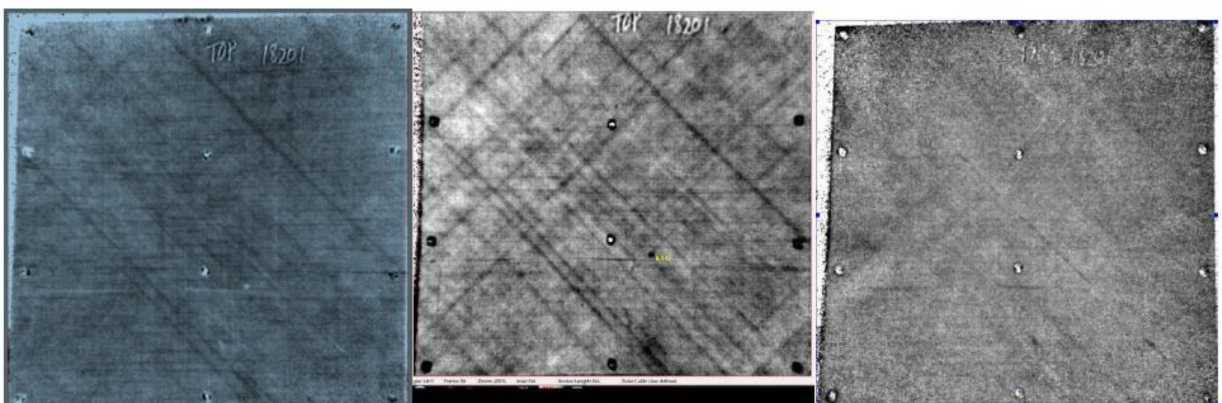
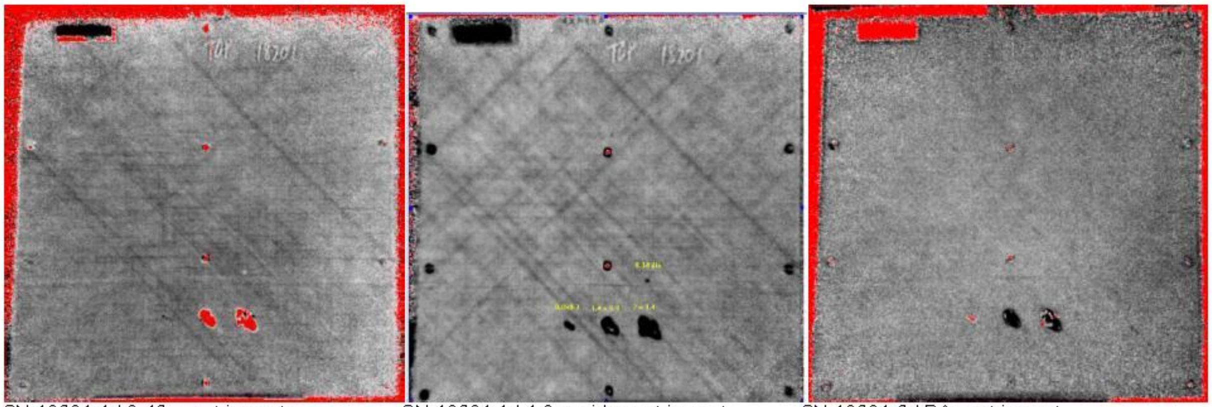


Figure 140: Before thermographic image of panel FIM-5.



SN 18201 1d 0.42s post impact SN 18201 1d 1.0s voids post impact SN 18201 2d PA post impact

Figure 141: After thermographic images of panel FIM-5.

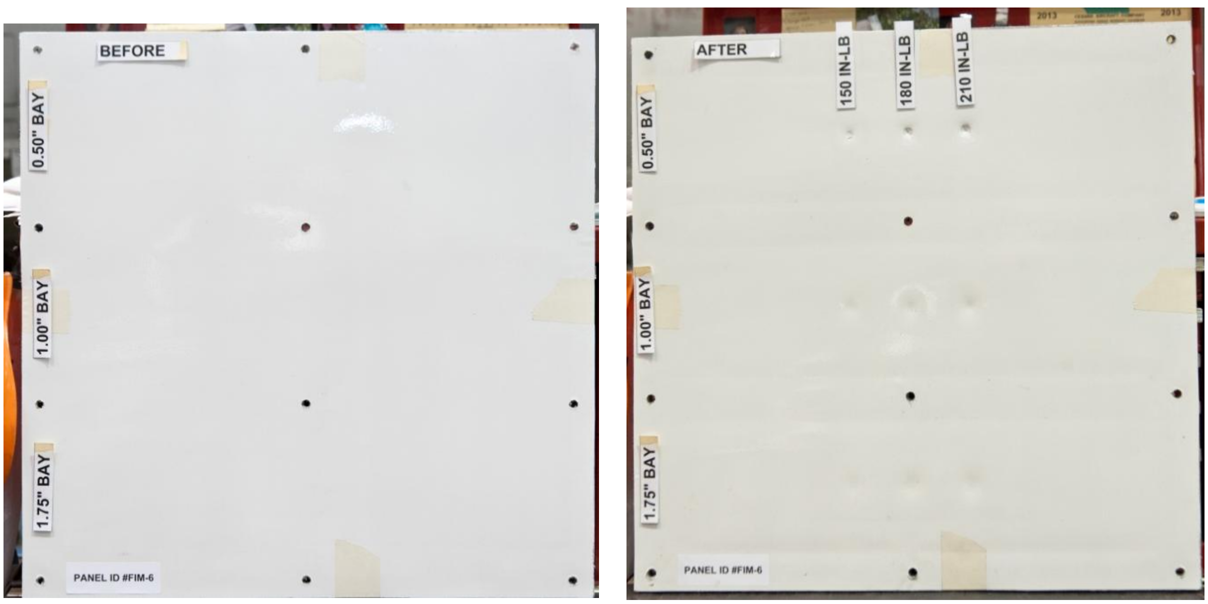


Figure 142: Before and after pictures of the front of panel FIM-6.

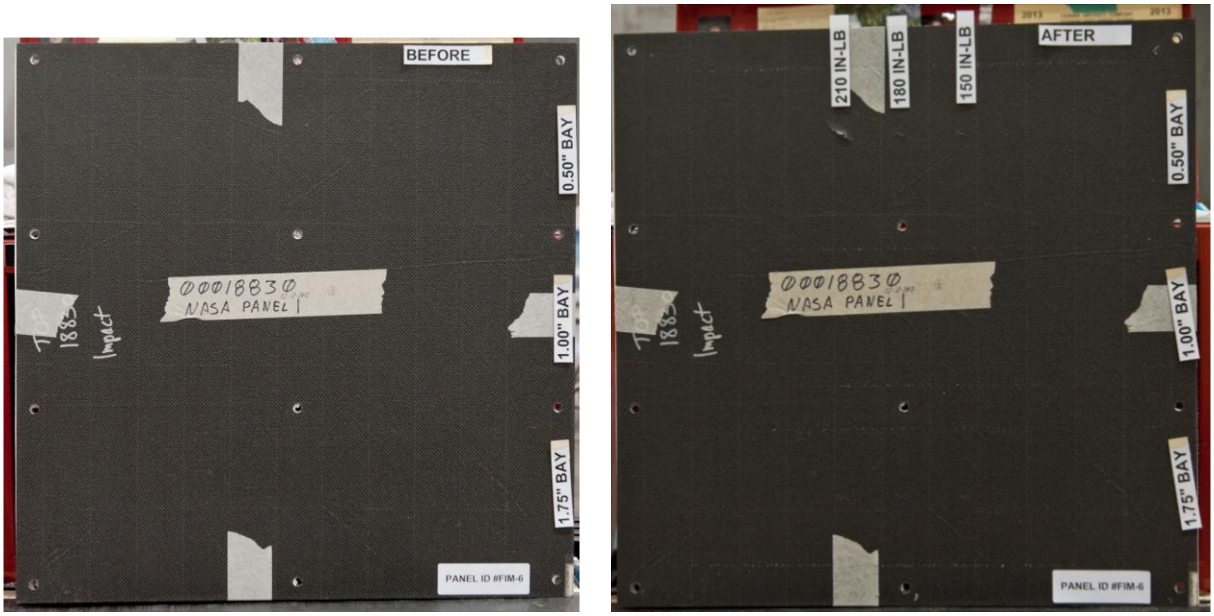


Figure 143: Before and after pictures of the back of panel FIM-6.

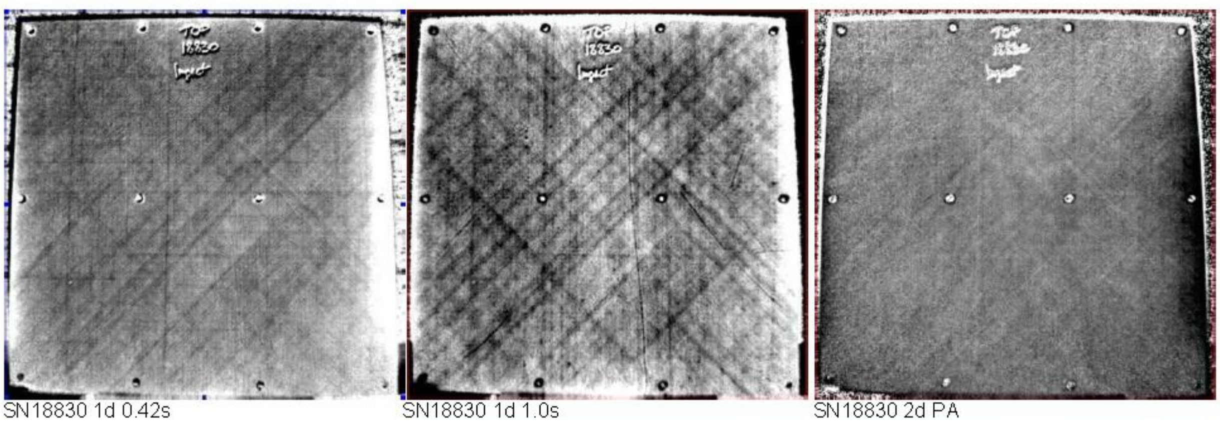
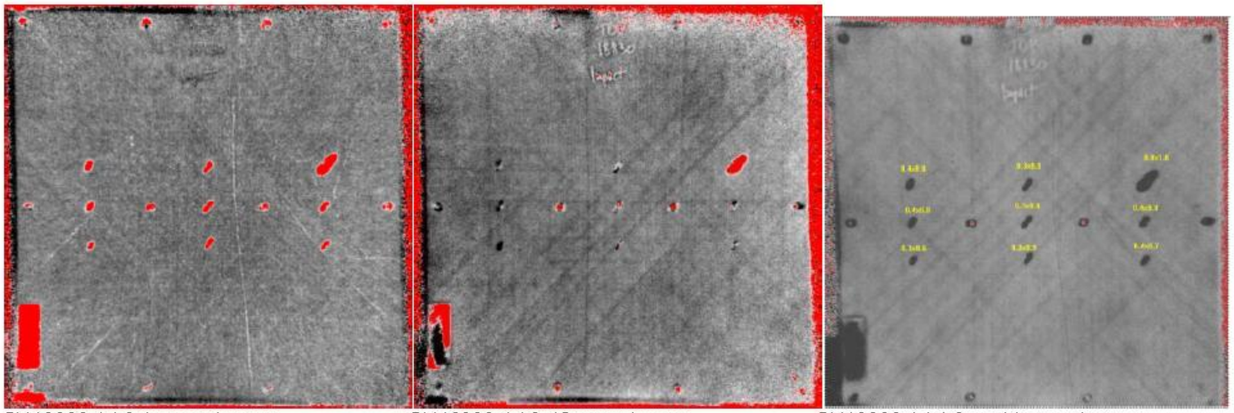


Figure 144: Before thermographic image of panel FIM-6.



SN18830 1d 0.1s post impact — SN18830 1d 0.42s post impact — SN18830 1d 1.0s voids post impact

Figure 145: After thermographic image of panel FIM-6.

The data which was collected from the impacts on panel FIM-3 came from the front and back views of the panel after impact as shown in Figure 130 and Figure 131. For reference, the pre-impact thermographic inspection image of FIM-3 is shown in Figure 132**.** The thermographic inspection made after impacting is shown in Figure 133**.**

The data was collected for panel FIM-3 in the same way that the data was collected for every panel. The data for FIM-3 is shown in Table 85. A description of the test data columns is presented in Table 86. There are nine lines of data for each test article. The first three are for the 0.5” impactor (shown in column 2) at 50, 180, and 250 in-lbs (shown in column 3); the next three are for the 1.0” impactor at the three energy levels; and the final three are for the 1.75” impactor at the three energy levels.

Table 85 shows that FIM-3 passed impact testing for 0.5” impactor at 150 and 180 in-lbs, 1.0” impactor at 150, 180, and 210 in-lbs, and 1.75” impactor at 150, 180, and 210 in-lbs. There are no cases for FIM-3 where visible damage is no and base panel damage is yes (which would violate the need to be able to visually detect actual damage). In fact, all cases tested have visible damage.

Table 85 - Impact Test Data Collected for Panel FIM-3

Panel	FIMpactor Dia	IN-LBS	Visible Damage	NDI Measurement (IN^2)	NDI Disposition	Base Panel Damage	Penetration (IN)	Comments
FIM-3	0.50	150	Y	0	A	N	0.21	Big diamond shaped impacts
FIM-3	0.50	180	Y	0.2	B	N	0.275	Big diamond shaped impacts
FIM-3	0.50	210	Y	0.7	D	Y	0.28	Big diamond shaped impacts
FIM-3	1.00	150	Y	0	A	N	0.117	Big diamond shaped impacts
FIM-3	1.00	180	Y	0	A	N	0.116	Big diamond shaped impacts
FIM-3	1.00	210	Y	0	A	N	0.121	Big diamond shaped impacts
FIM-3	1.75	150	Y	0	A	N	0.101	Big diamond shaped impacts
FIM-3	1.75	180	Y	0	A	N	0.104	Big diamond shaped impacts
FIM-3	1.75	210	Y	0	A	N	0.115	Big diamond shaped impacts

Table 86 - Description of Test Data Columns

Impactor Diameter (inches):	Size of the impactor (0.5, 1.0, 1.75).
Force Applied (in-lbs):	The amount of force applied (150, 180, 210).
Visible damage:	Visible at 5 feet by untrained personnel (Category 3).
NDI Disposition:	Base panel damage area measured by Thermography. A=0.000 to 0.062 sq. in., B=0.063 to 0.25 sq. in., C=>0.25 to 0.56 sq. in., D=>0.56 to 1.00 sq. in., E=>1.00 sq.in. (Catecoy C, D, and E are failures.)
Base Panel Damage:	Visible damage to base (structural) panel.
Penetration (in):	Protective skin penetration measured with depth gauge.

Table 87 contains all of the data for all of the test articles. Table 87 shows that all of the impacts were visible on the protective skin; no test articles were eliminated from consideration because the protective skin hid damage.

Table 87 - Second-Generation Skins Impact Test Data (1 of 2)

Panel	FIMpactor Dia	IN-LBS	Visible Damage	NDI Measurement (IN^2)	NDI Disposition	Base Panel Damage	Penetration (IN)	Comments
FIM-0	0.50	150	Y	1.3	E	Y	0.276	
FIM-0	0.50	180	Y	1.5	E	Y	0.301	
FIM-0	0.50	210	Y	2.3	E	Y	0.253	
FIM-0	1.00	150	Y	2	E	Y	0.158	
FIM-0	1.00	180	Y	2.5	E	Y	0.25	
FIM-0	1.00	210	Y	2.5	E	Y	0.267	
FIM-0	1.75	150	Y	1.4	E	Y	0.005	Did not break completely through to back side
FIM-0	1.75	180	Y	1.7	E	Y	0.017	Did not break completely through to back side
FIM-0	1.75	210	Y	2.6	E	Y	0.015	Did not break completely through to back side
FIM-1	0.50	150	Y	0.61	D	Y	0.046	
FIM-1	0.50	180	Y	0.61	D	Y	0.079	
FIM-1	0.50	210	Y	0.74	D	Y	0.081	
FIM-1	1.00	150	Y	0	A	N	0.03	
FIM-1	1.00	180	Y	0.61	D	Y	0.032	
FIM-1	1.00	210	Y	0.38	C	N	0.034	
FIM-1	1.75	150	Y	0	A	N	0.021	
FIM-1	1.75	180	Y	0.61	D	Y	0.015	
FIM-1	1.75	210	Y	0.38	C	N	0.017	
FIM-2	0.50	150	Y	0.35	C	N	0.109	
FIM-2	0.50	180	Y	0.48	C	N	0.14	
FIM-2	0.50	210	Y	1.68	E	Y	0.161	
FIM-2	1.00	150	Y	0	A	N	0.059	
FIM-2	1.00	180	Y	0.15	B	N	0.073	
FIM-2	1.00	210	Y	0.56	C	N	0.077	
FIM-2	1.75	150	Y	0	A	N	0.019	
FIM-2	1.75	180	Y	0.12	B	N	0.018	
FIM-2	1.75	210	Y	0.12	B	N	0.02	
FIM-3	0.50	150	Y	0	A	N	0.21	Big diamond shaped impacts
FIM-3	0.50	180	Y	0.2	B	N	0.275	Big diamond shaped impacts
FIM-3	0.50	210	Y	0.7	D	Y	0.28	Big diamond shaped impacts
FIM-3	1.00	150	Y	0	A	N	0.117	Big diamond shaped impacts
FIM-3	1.00	180	Y	0	A	N	0.116	Big diamond shaped impacts
FIM-3	1.00	210	Y	0	A	N	0.121	Big diamond shaped impacts
FIM-3	1.75	150	Y	0	A	N	0.101	Big diamond shaped impacts
FIM-3	1.75	180	Y	0	A	N	0.104	Big diamond shaped impacts
FIM-3	1.75	210	Y	0	A	N	0.115	Big diamond shaped impacts

Table 87 - Second-Generation Skins Impact Test Data (2 of 2)

Panel	FIMpactor Dia	IN-LBS	Visible Damage	NDI Measurement (IN^2)	NDI Disposition	Base Panel Damage	Penetration (IN)	Comments
FIM-4	0.50	150	Y	0.07	B	N	0.128	
FIM-4	0.50	180	Y	0.38	C	N	0.14	
FIM-4	0.50	210	Y	0	A	N	0.16	
FIM-4	1.00	150	Y	0	A	N	0.056	
FIM-4	1.00	180	Y	0	A	N	0.056	
FIM-4	1.00	210	Y	0	A	N	0.067	
FIM-4	1.75	150	Y	0	A	N	0.043	
FIM-4	1.75	180	Y	0	A	N	0.045	
FIM-4	1.75	210	Y	0	A	N	0.054	
FIM-5	0.50	150	Y	0.24	B	N	0.14	
FIM-5	0.50	180	Y	1.26	E	Y	0.177	
FIM-5	0.50	210	Y	2.8	E	Y	0.303	
FIM-5	1.00	150	Y	0	A	N	0.138	
FIM-5	1.00	180	Y	0	A	N	0.134	
FIM-5	1.00	210	Y	0	A	N	0.136	
FIM-5	1.75	150	Y	0	A	N	0.031	
FIM-5	1.75	180	Y	0	A	N	0.088	
FIM-5	1.75	210	Y	0	A	N	0.095	
FIM-6	0.50	150	Y	0.28	C	N	0.07	Could feel but not see back side damage
FIM-6	0.50	180	Y	0.27	C	N	0.15	Could feel but not see back side damage
FIM-6	0.50	210	Y	1.44	E	Y	0.201	
FIM-6	1.00	150	Y	0.27	C	N	0.025	Could feel but not see back side damage
FIM-6	1.00	180	Y	0.24	B	N	0.034	Could feel but not see back side damage
FIM-6	1.00	210	Y	0.27	C	N	0.047	Could feel but not see back side damage
FIM-6	1.75	150	Y	0.18	B	N	0.018	
FIM-6	1.75	180	Y	0.32	C	N	0.035	
FIM-6	1.75	210	Y	0.32	C	N	0.035	

8.2.5 *Data Analysis*

8.2.5.1 ***NDI Analysis***

In order to start to make sense out of the data, the raw data in Table 87 was reorganized to have one line per impact panel with only the protective skin areal weight and the NDI rating for each impactor and each energy level as shown in Table 88. The "A", "B", "C", "D", and "E" NDI ratings were converted to numerical values "0", "1", "2", "3", and "4" where 0 corresponds to A (no damage) and 4 corresponds to E (maximum damage). The NDI ratings have been color coded to help visually inspect the data. An NDI rating of 0 (A), 1 (B), or 2 (C) was deemed to be passing. The average NDI rating (sum of each NDI

rating for a panel divided by 9) is also shown. An average NDI rating of 0 means that the panel passed all impact cases; similarly, an average NDI rating of 4 means the panel failed all impact cases. The average does not provide any insight into which impact conditions were failed for non-zero average NDI ratings.

Table 88 - Reformatted Data

					.5" Impactor			1.0" Impactor			1.75" Impactor			
Panel	Absorbing Layer	Absorb T	Spreading Layer	psf	150	180	210	150	180	210	150	180	210	Average
FIM-0	None	0.000	None	0.000	4	4	4	4	4	4	4	4	4	4.000
FIM-6	Polydamp	0.500	Innegra	0.245	2	2	4	2	1	2	1	2	2	2.000
FIM-3	3# honeycomb	0.250	Innegra	0.455	0	1	3	0	0	0	0	0	0	0.444
FIM-2	3 mm Soric LRC	0.118	Carbon ALS	0.550	2	2	4	0	1	2	0	1	1	1.444
FIM-5	10# PU core	0.250	Carbon ALS	0.605	1	4	4	0	0	0	0	0	0	1.000
FIM-1	3 mm Soric LRC	0.118	Innegra	0.645	3	3	3	0	3	2	0	3	2	2.111
FIM-4	10# PU core	0.250	Innegra	0.655	1	3	0	0	0	0	0	0	0	0.444

None of the test articles shown in Table 88 successfully resisted all of the impact conditions (with a 2 or less NDI rating). This is probably not surprising for two reasons: 1) the minimum impact was raised to 150 in-lbs from 50 in-lbs; and 2) the second-generation test articles used the data from the first-generation articles to minimize the amount of material in the test articles (these were expected to be "on the edge").

As was mentioned in Section 2.0 Requirements, a realistic pass condition for the panels is to pass the 0.5" impactor at 150 in-lbs, the 1.0" impactor at 150 and 180 in-lbs, and to pass the 1.75" impactor at all energy levels. Table 89 shows only those impact conditions in the columns under each impactor diameter. All but panel FIM-0 (with no protective skin) and FIM-1 pass all of the realistic conditions

Table 89 - Realistic Impact Conditions Results Sorted in Increasing Protective Skin Areal Density

					.5" Impactor	1.0" Impactor		1.75" Impactor			
Panel	Absorbing Layer	Absorb T	Spreading Layer	psf	150	150	180	150	180	210	Average
FIM-0	None	0.000	None	0.000	4	4	4	4	4	4	4.000
FIM-6	Polydamp	0.500	Innegra	0.245	2	2	1	1	2	2	2.000
FIM-3	3# honeycomb	0.250	Innegra	0.455	0	0	0	0	0	0	0.444
FIM-2	3 mm Soric LRC	0.118	Carbon ALS	0.550	2	0	1	0	1	1	1.444
FIM-5	10# PU core	0.250	Carbon ALS	0.605	1	0	0	0	0	0	1.000
FIM-1	3 mm Soric LRC	0.118	Innegra	0.645	3	0	3	0	3	2	2.111
FIM-4	10# PU core	0.250	Innegra	0.655	1	0	0	0	0	0	0.444

The panels are sorted by areal density in Table 89. The lowest areal density is the base substrate panel (FIM-0) with a protective skin psf of 0 since there is no protective skin. Next lightest is panel FIM-6 (the Polydamp hydrophobic) with a protective skin areal density of 0.245 psf which is significantly below the target. FIM-3 is close to the upper bound of the weight target. Panels FIM-4 and FIM-5 are the two polyurethane panels – they are very heavy, with areal densities over 0.6 psf.

FIM-1 (with 3 mm Soric LRC for impact absorbing and Innegra for impact spreading) is very heavy (0.645 psf) and failed the impact test at both the set impact condition (180 in-lbs with a 1.0" impactor) and at the other realistic impact conditions. The manufacturing process used true VARTM (Vacuum Assisted Resin Transfer Molding). Both the Soric and Innegra were difficult to get fully wetted with the wet layup technique used for the first-generation test articles. This

panel is considerably heavier than the first-generation panels, suggesting that the VARTM process was more effective in getting resin into the Soric and Innegra. Perhaps that more solid resin resulted in a more brittle test article, as suggested by significant delamination with both the 1.0" and 1.75" impactors at 180 in-lbs.

Panel FIM-2 differs from Panel FIM-1 only in the Carbon ALS rather than Innegra as the impact spreading layer. Carbon ALS was not used in the first-generation test articles, but Carbon (without the aluminum lightning strike protection wires) was used. The Carbon wetted very well using the wet layup technique on the first-generation test articles. FIM-2 with Carbon ALS was not as heavy as FIM-1 with Innegra. The pattern of delamination is similar but at a reduced and acceptable level (1 or up to 0.25 sq. in.), suggesting that perhaps less of the "brittle" resin reduced the impact damage.

8.2.6 Impact Depth Analysis

The actual impact depths were measured for these panels. The measured depths are shown in the seventh column (Penetration (in)) in Table 87. Figure 146 contains the penetration depths for all panels with the 0.5" impactor, Figure 147 contains the depths for the 1.0" impactor, and Figure 148 for the 1.75" impactor. Not unexpectedly, the impact depths tend to be greatest for the 0.5" impactor and least for the 1.75" impactor.

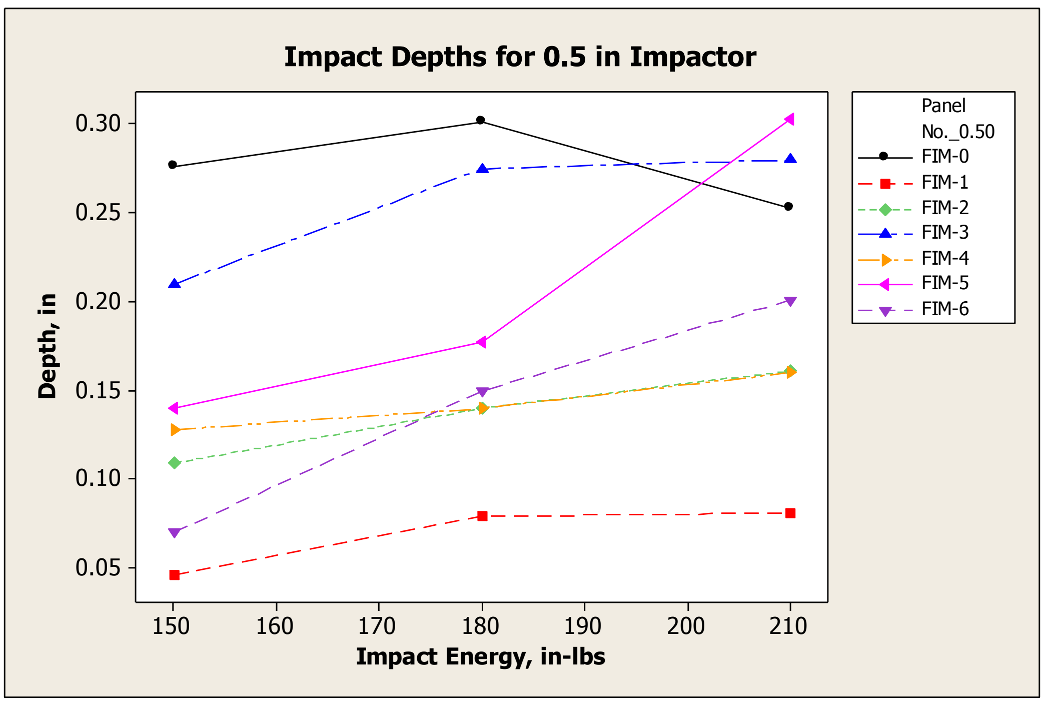


Figure 146: Impact depths for the 0.5" impactor.

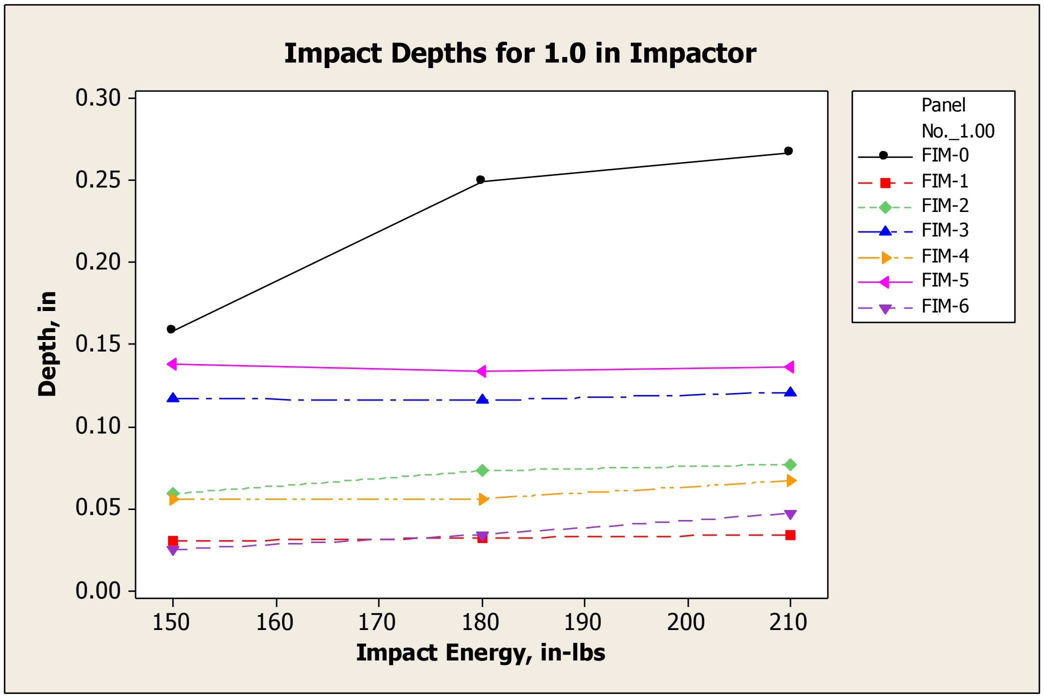


Figure 147: Impact depths for the 1.0" impactor.

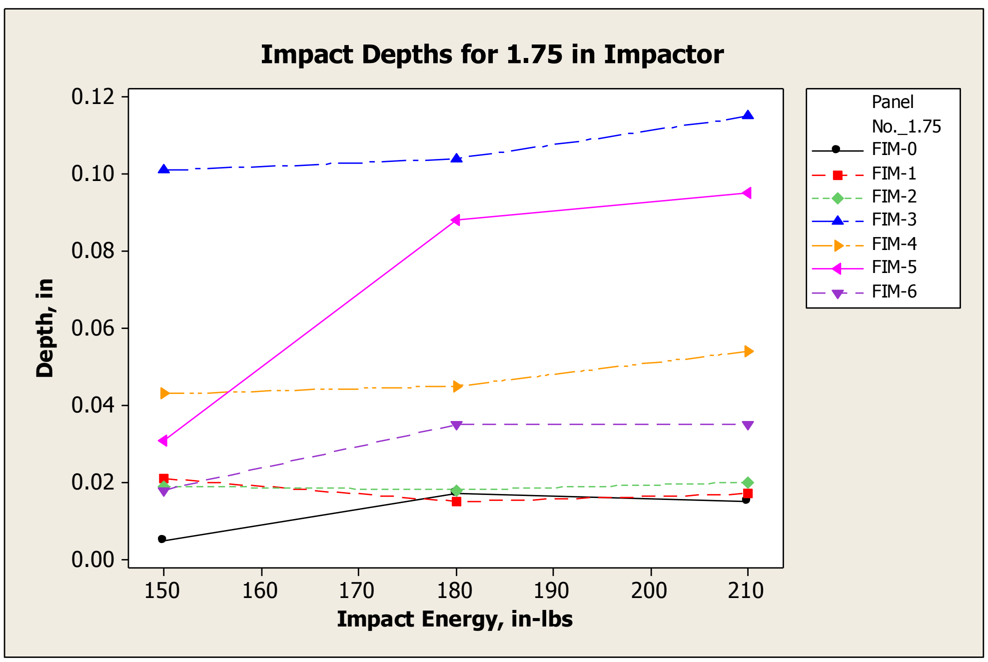


Figure 148: Impact depths for the 1.75" impactor.

Of interest about these graphs are the differences in impact depths between FIM-1 and FIM-2 and FIM-4 and FIM-5 where the difference in materials is Innegra and LDS 50-01 or Carbon ALS. In all cases, the carbon ALS panels have a greater impact depth. For the 1.75" impactor where the depths are fairly small anyway, the actual differences between FIM-1 and FIM-2 are almost the same. Otherwise, the Carbon ALS panels have a noticeably greater impact depth (especially for the polyurethane core of

panels FIM-4 and FIM-5). This is consistent with the visual observations as seen in Figure 149 and Figure 150.

Figure 149: FIM-1 (left) and FIM-2 (right) after impacts.

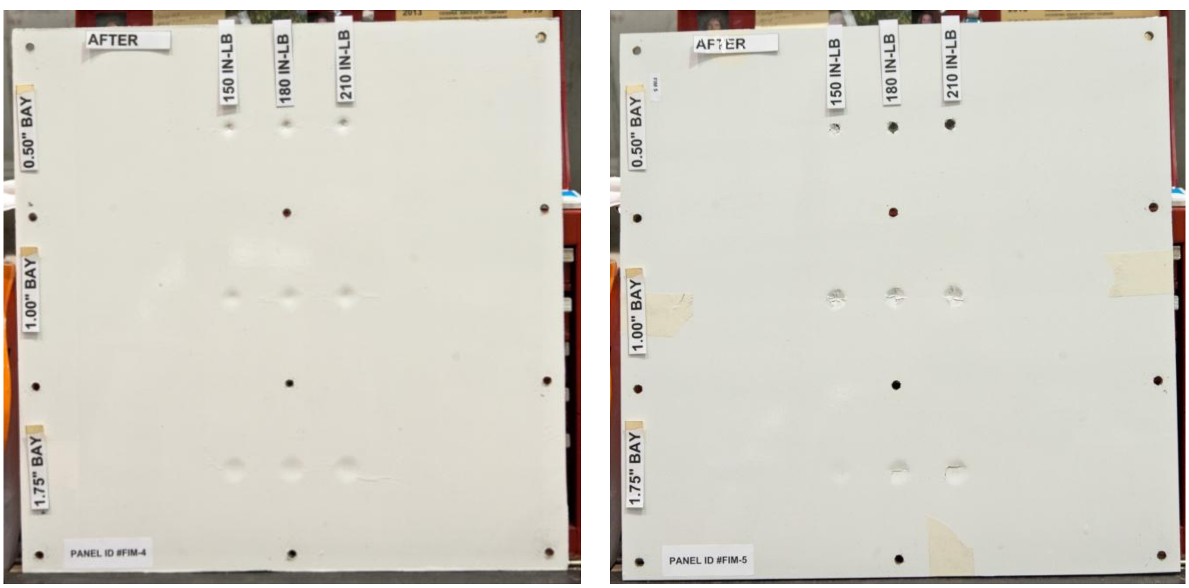


Figure 150: FIM-4 (left) and FIM-5 (right) after impacts.

Also of interesting note is that the Innegra panels (FIM-1 and FIM-4) are heavier than the Carbon ALS panels (FIM-2 and FIM-5) as was shown in Table 87. Carbon ALS is heavier than Innegra. However, the Carbon ALS has lightning protection included while the Innegra has LDS 50-01 added. While the LDS 50-01 has an areal density of only 0.07 psf, it is possible that the vacant spaces in the LDS 50-01 also harbor resin and increase the weight.

8.2.7 *Final Thoughts on Impact Testing Results*

Impact testing, consisting of three impactor diameters and three energy levels, was conducted on six second-generation panels along with one base substrate panel. Before and after impact pictures were taken and thermographic inspection was performed on each panel. All of the panels except FIM-1 passed. The Polydamp Hydrophobic test article had acceptable amounts of delamination at all impact energies of interest and was below the weight target. The thinner material with an impact spreading layer worked very well.

8.3 Electromagnetic Effects

The purpose of this testing is to evaluate the second generation of STAR-C^2 protective skin test panels for shielding effectiveness, direct effects of lightning (DEL), and indirect effects of lightning (IEL). Testing for the second-generation panels was conducted in the same manner as for the first-generation panels. The test results are separated into three parts: shielding effectiveness, IEL and DEL. Data graphs, pictures, and test log scans are provided in the following subsections and the attached appendices.

8.3.1 *Test Articles*

The second-generation lightning strike test articles were built with the materials described in Table 77. The measured and calculated weights to determine the areal density of the protective skins are shown in Table 90. The protective skin weight shown here is without the backing on the double-sided tape on the test articles.

Table 90 - Second-Generation Lightning Strike Test Article Weights

Test Article No.	Panel No.	Total Weight (lbs)	Panel Weight (lbs)	Protective Skin Weight (lbs)	Areal Density* (lbs/ft^2)
FLS-1	18168	3.54	1.52	2.02	0.601
FLS-2	18163	3.38	1.50	1.88	0.559
FLS-3	18162	2.94	1.48	1.46	0.434
FLS-4	18170	3.74	1.50	2.24	0.666
FLS-5	18161	3.57	1.50	2.07	0.616
FLS-6	18169	2.19	1.50	0.69	0.205

*Aerial density based on 22" x 22" of protective skin area

8.3.2 *Transmissivity/Shielding Effectiveness (HIRF)*

The transmissivity testing for the second-generation panels was conducted in exactly the same way with exactly the same test equipment as the first-generation panels. The panels were installed in the window of the reverberation chambers with the protective skin side layer facing the transmitter antenna in the larger reverberation chamber using a frame fabricated at Cessna. All panels were taped with copper tape with conducting adhesive to prevent currents from wrapping around the other side of the frame.

The aluminum panel used to generate results for comparison is shown mounted in the chamber in Figure 151. The second-generation plain base substrate panel (7-layered carbon fiber composite panel without any protective skin including lightning strike protection) mounted in the chamber is shown in Figure 152. Figure 153 shows FLS-1 mounted in the chamber, FLS-2 is shown in Figure 154, FLS-3 is

shown in Figure 155, Figure 156 shows FLS-4 mounted in the chamber, FLS-5 is shown in Figure 157, and FLS-6 is shown mounted in the chamber in Figure 158.

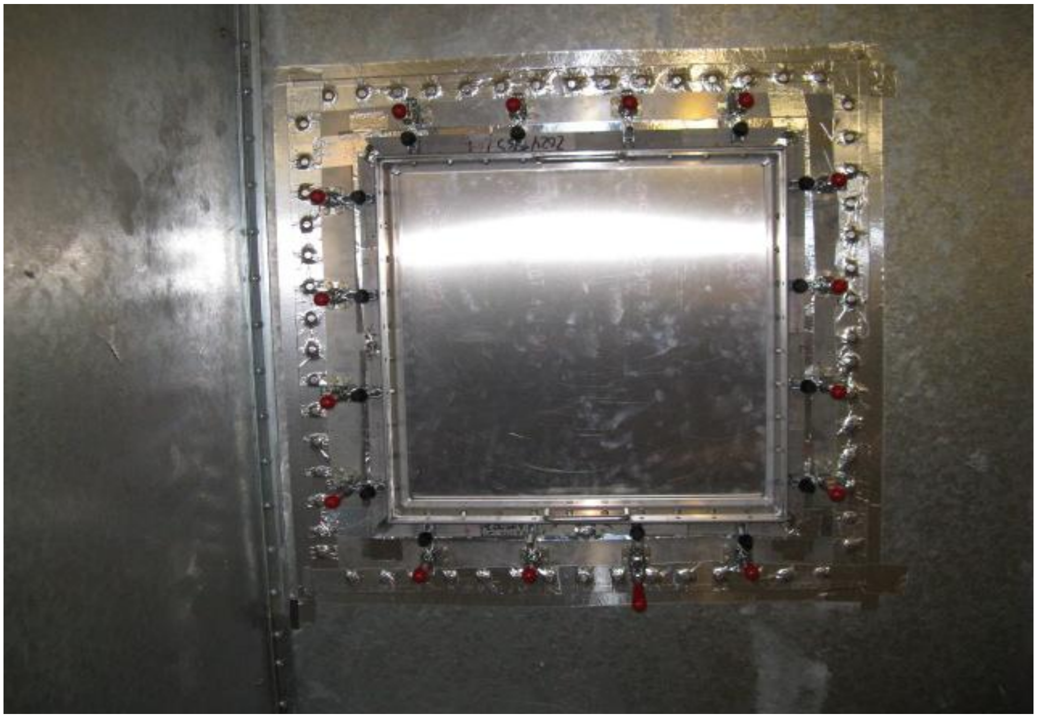


Figure 151: Aluminum panel installed in the window.

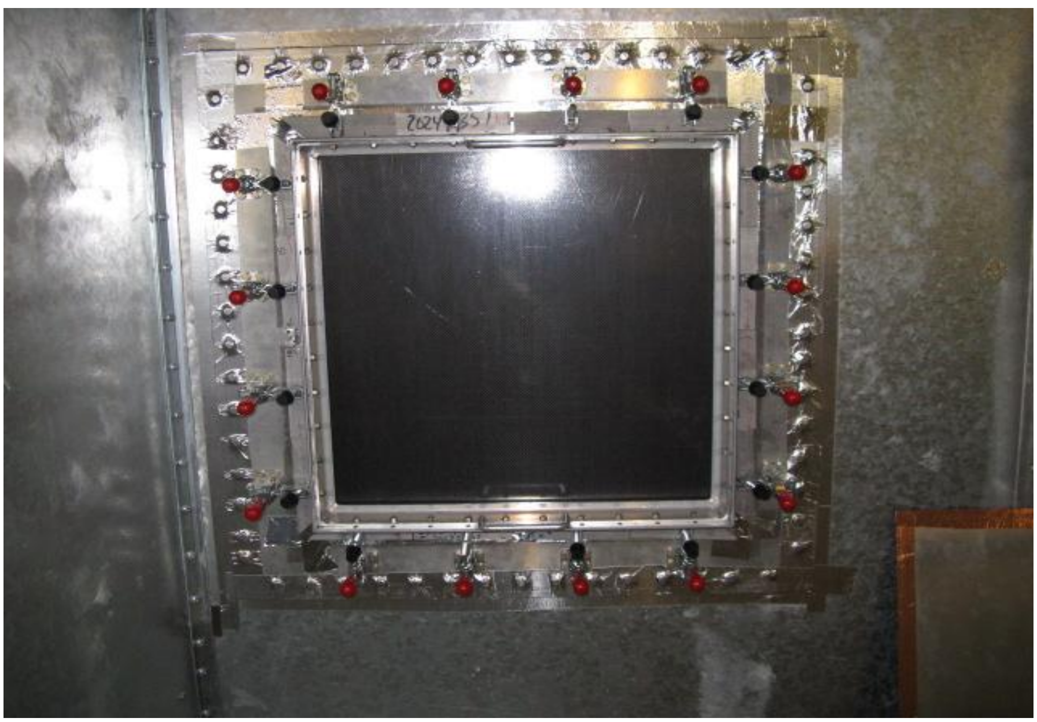


Figure 152: CFC panel installed in the window.

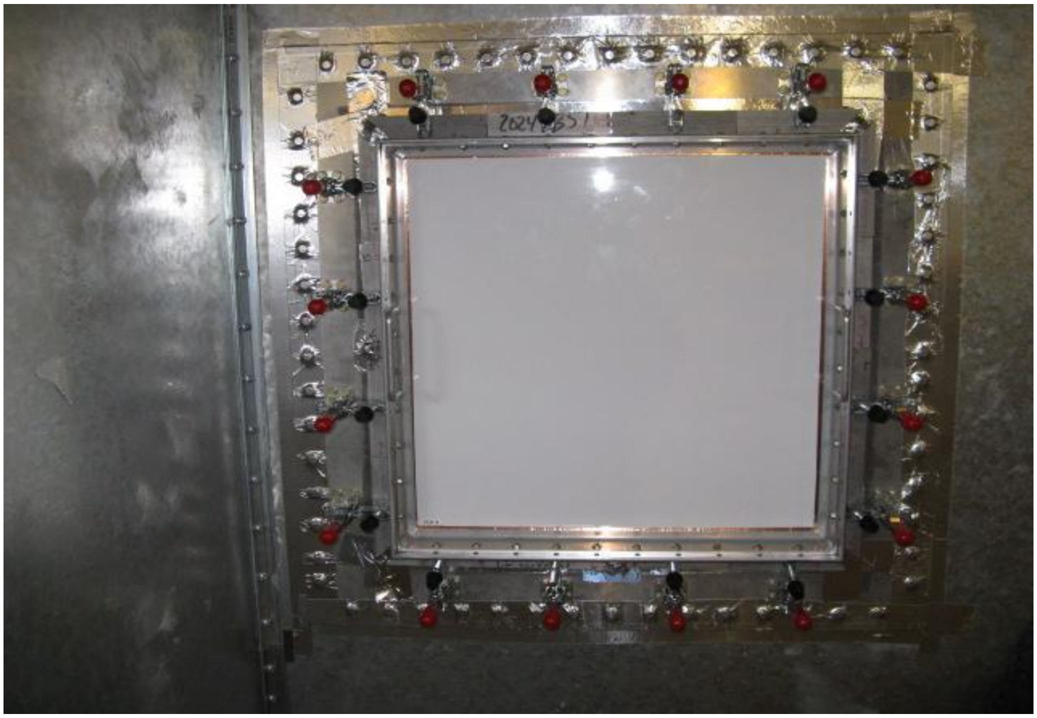


Figure 153: FLS-1 panel installed in the window.

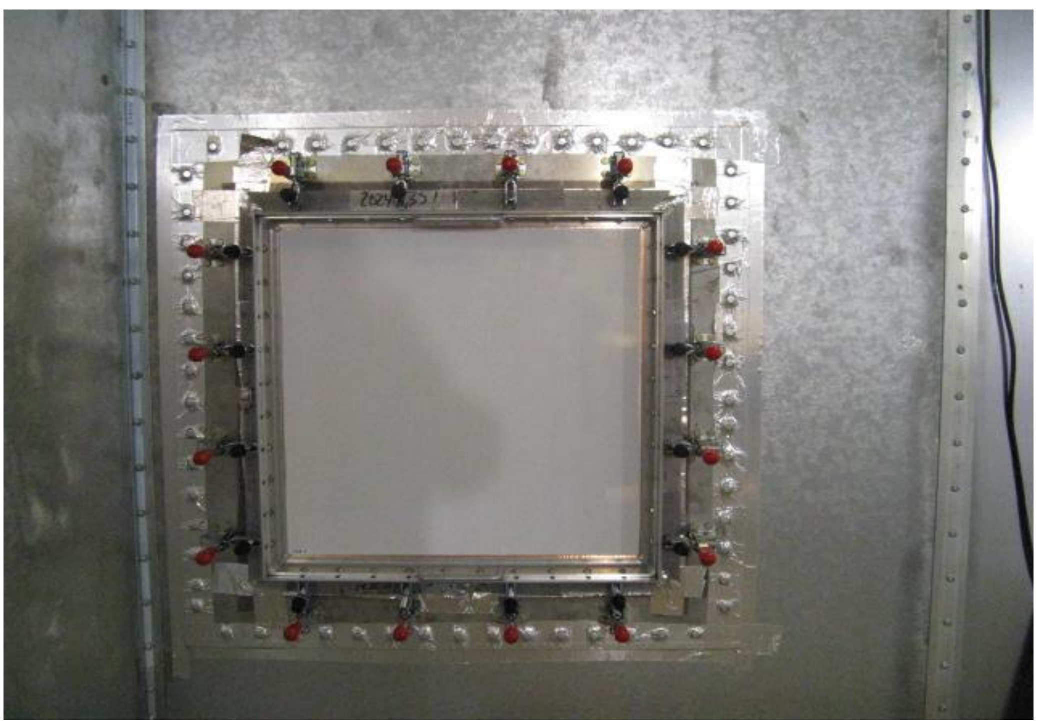


Figure 154: FLS-2 panel installed in the window.

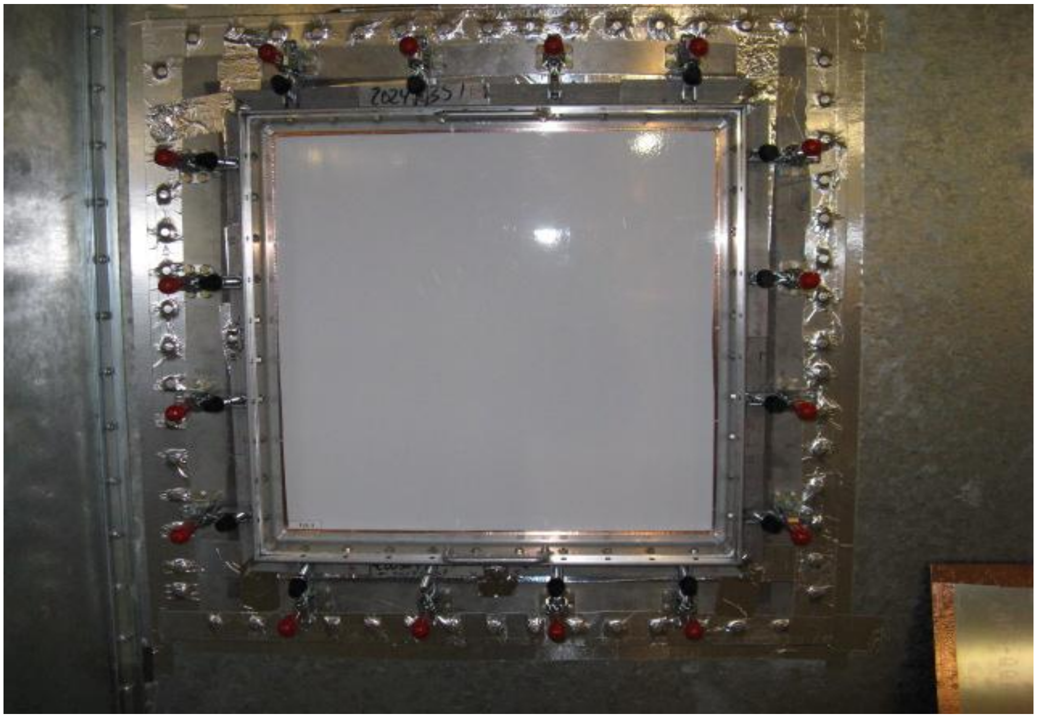


Figure 155: FLS-3 panel installed in the window.

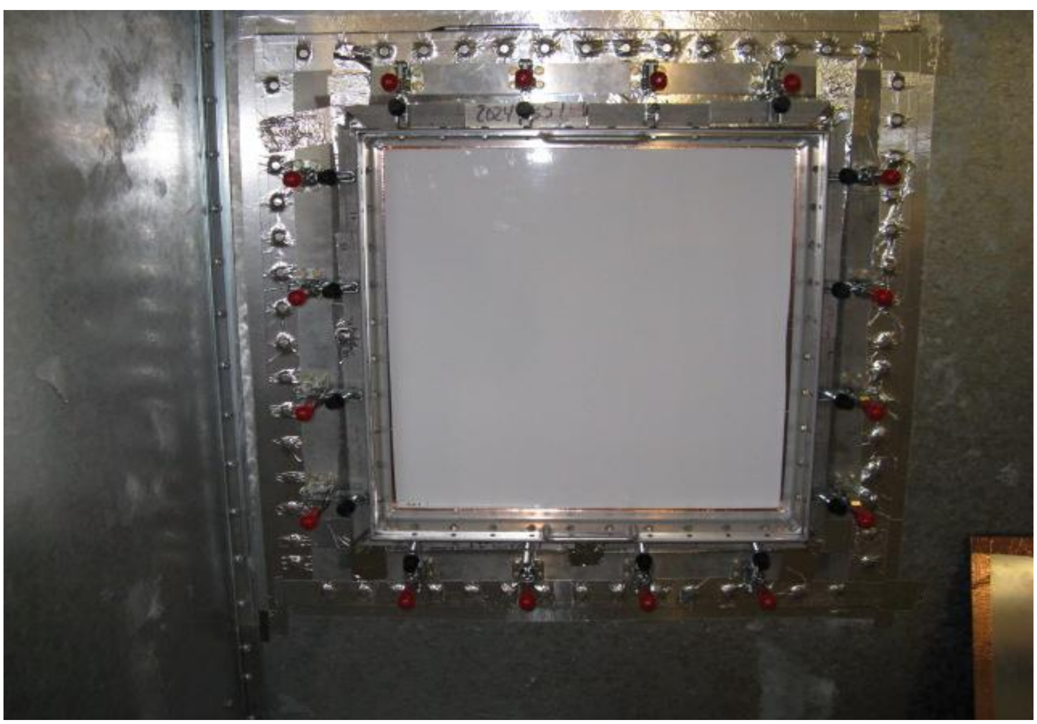


Figure 156: FLS-4 panel installed in the window.

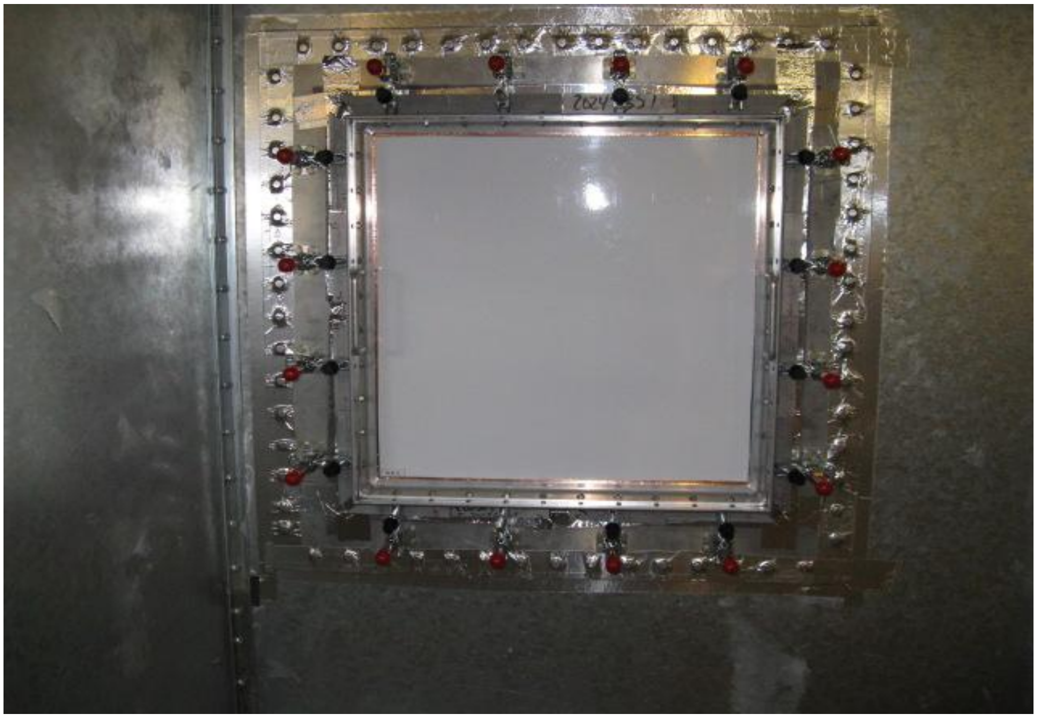


Figure 157: FLS-5 panel installed in the window.

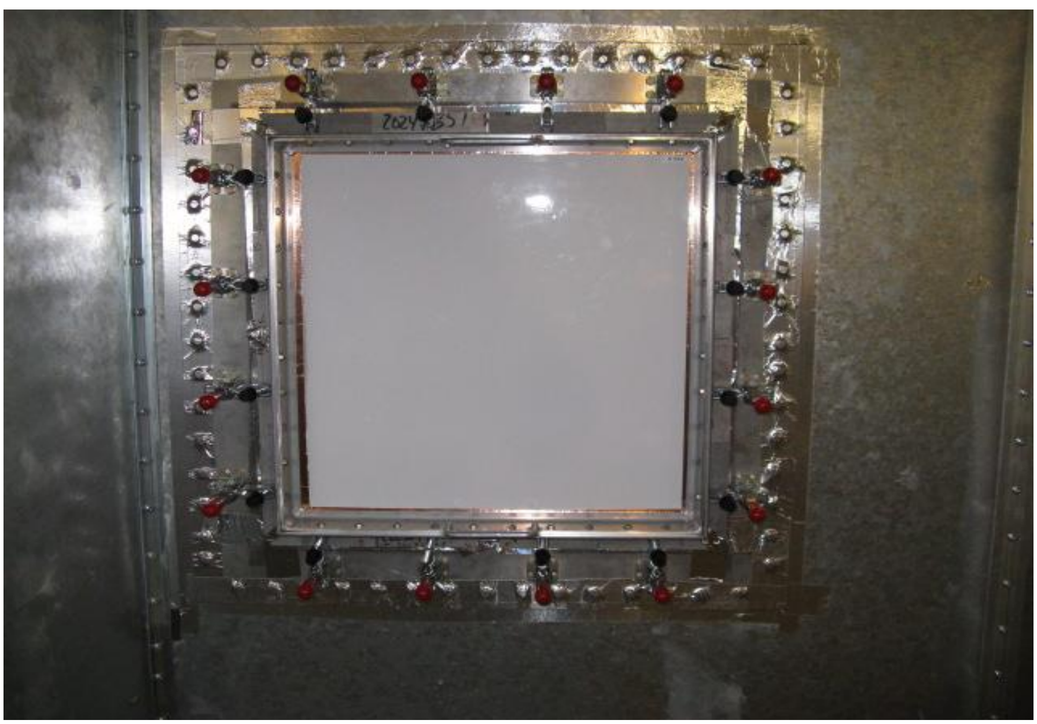


Figure 158: FLS-6 panel installed in the window.

Baseline results were generated with the open window and window closed with 2024 T3 bare 24” x 24” inch 0.063” aluminum (Al) skin. This represents the best case (metal sealed window) and worst case (open window) extremes for use in the relative measurement of the panels. The insertion loss of the reverberation chamber was measured using the top hat antenna in the main chamber and then used for the correction factor. Shielding effectiveness data in the following plots is represented using the first order correction where the chamber loss is added to the receive signal and plotted on the y-axis. Three test runs of the Al panel in the window on three different days showed variation in the range of 3-8GHz due to the setup. Hence comparison of the shielding effectiveness will be from 700MHz to 2 GHz.

Figure 159 shows the comparison between the open window, the Al panel, and the second-generation base substrate panel. Addition of the protective skins is necessary to produce shielding effectiveness results closer to aluminum. Shielding effectiveness testing of the panels gives an insight into materials to be chosen to get close to the shielding effectiveness of aluminum.

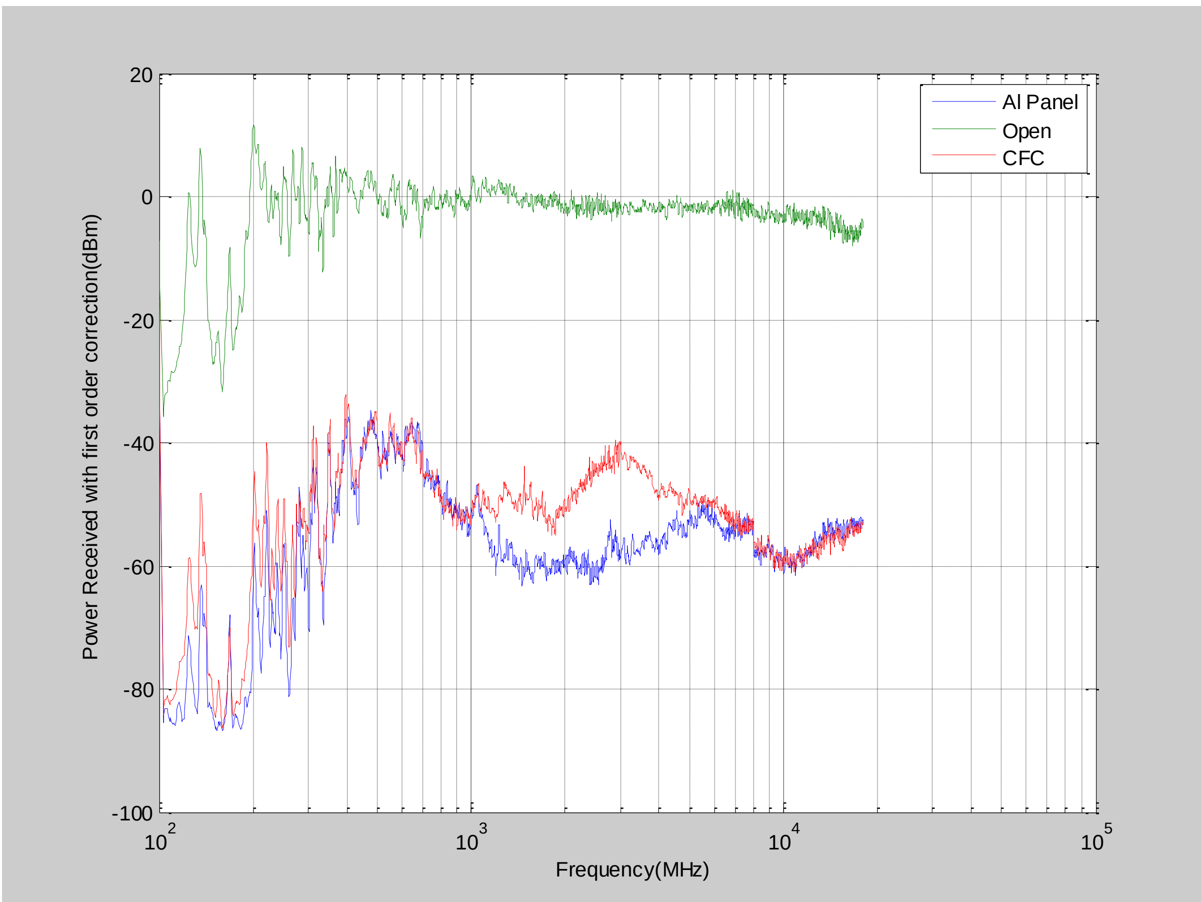


Figure 159: Shielding effectiveness of a base substrate panel.

Figure 160 shows a plot of shielding effectiveness of with and without a software filter. All the data was filtered using a software filter with moving average of 5 points in MATLAB. Figure 161 shows the comparison of lightning strike materials LDS 50-01 and ALS interwoven in CFC with the same base core of 3mm Soric with Integument Film with PSA. These show that the difference at various frequencies is less than 1dBm transmissivity.

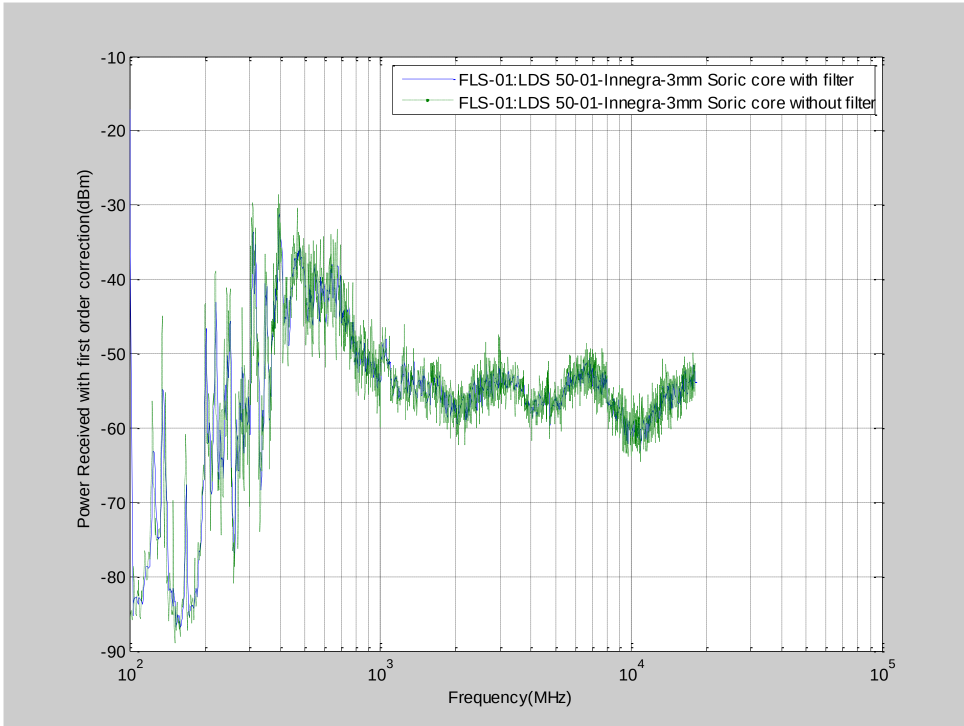


Figure 160: Shielding effectiveness of Panel FLS-1 with and without software filter.

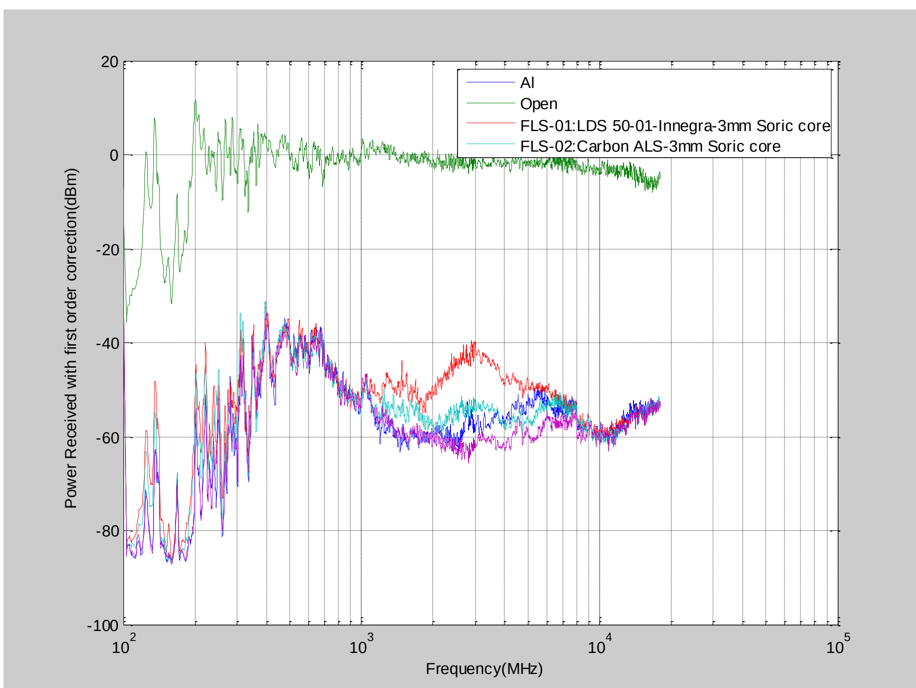


Figure 161: Shielding effectiveness of lightning strike materials with 3mm Soric core with base substrate panel compared to an Al panel and open window.

Figure 162 shows the shielding effectiveness of the panel with Polydamp core and LDS50-01 lightning strike material compared to CFC and Aluminum. The shielding effectiveness for the Polydamp is less than CFC by 15 dBm at 3 GHz. Figure 163 shows the shielding effectiveness of different core materials with respect to the same lightning strike material LDS 50-01. In comparison, the power received is almost equivalent. Figure 164 compares the polyurathene core to honeycomb core where both use the LDS 50-01 lightning strike material. Figure 165 compares two different lightning strike materials with the polyurethane core. There is no substantial difference in the shielding effectiveness. Figure 166 and Figure 167 show the shielding effectiveness of all the panels. The minimum shielded panel is the bare CFC panel without any protective skin (including lightning strike material).

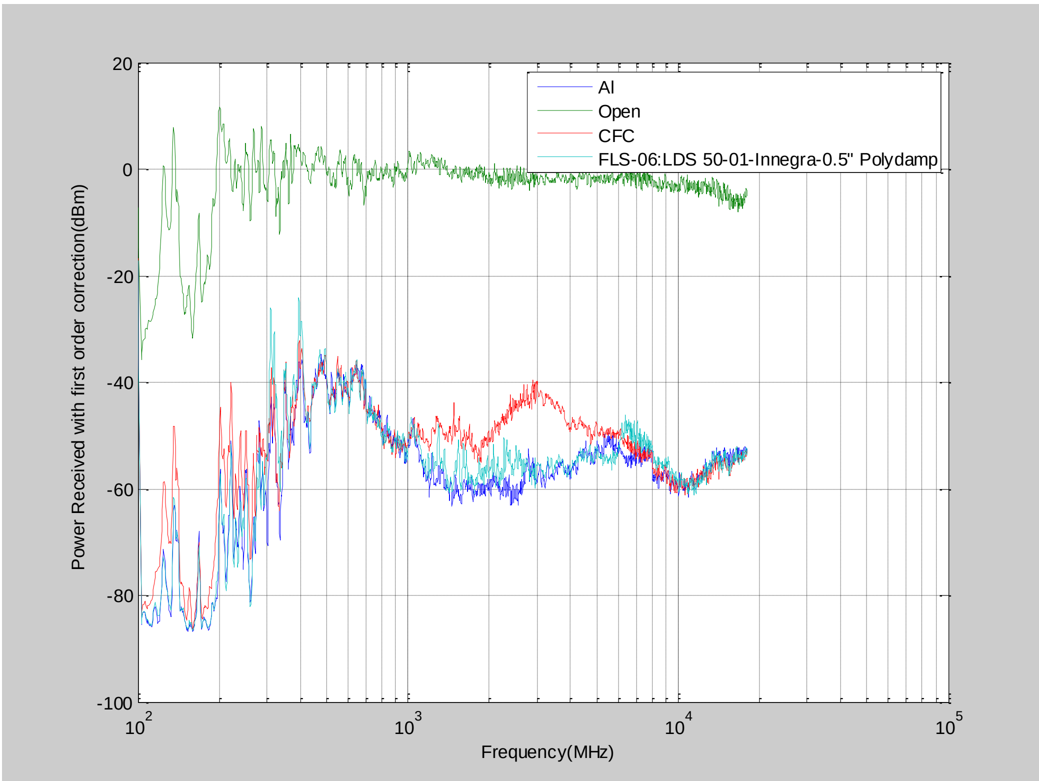


Figure 162: Shielding effectiveness of panel FLS-6 with polydamp core with base substrate panel compared to an Al panel and open window.

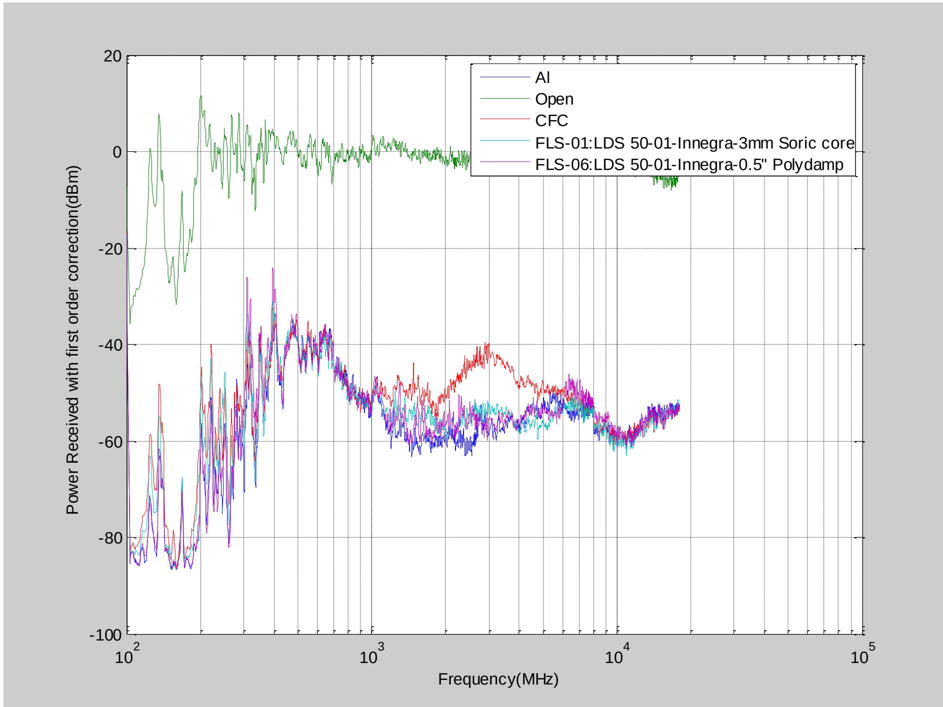


Figure 163: Shielding effectiveness of lightning strike material with 3mm Soric core and Polydamp core with base substrate panel compared to an Al panel and open window.

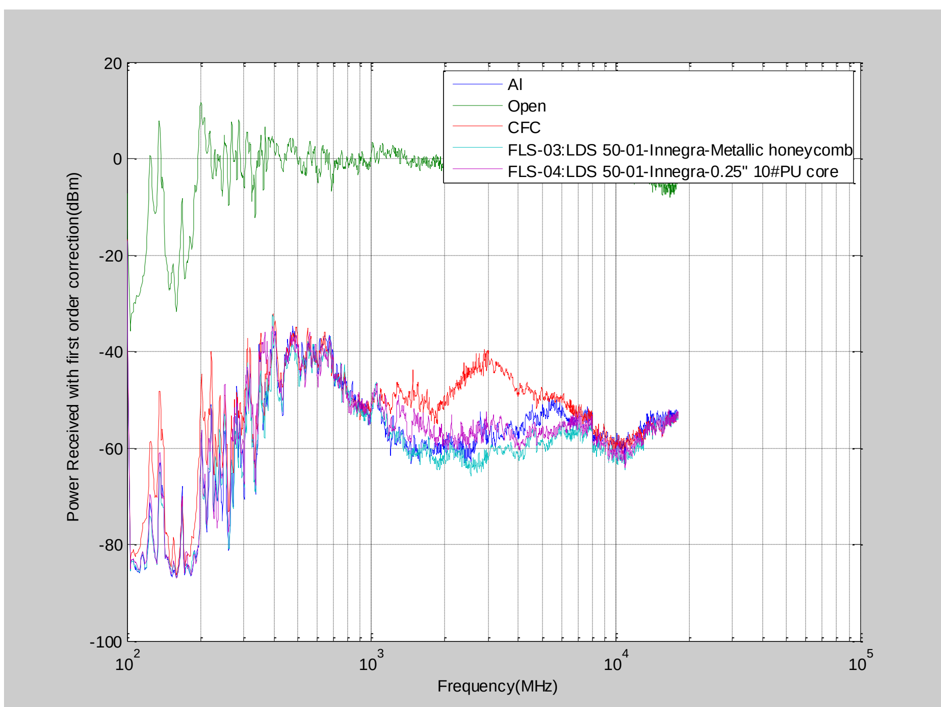


Figure 164: Shielding effectiveness of lightning strike material with honeycomb and polyurethane core with base substrate panel compared to an Al panel and open window.

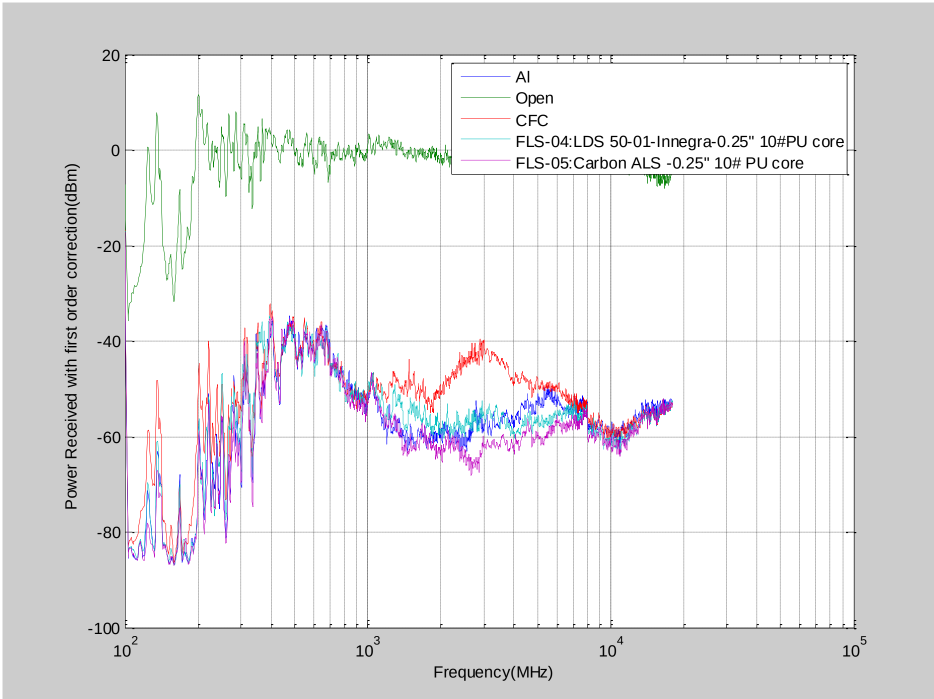


Figure 165: Shielding effectiveness of lightning strike material with polyurathene core with base substrate panel compared to an Al panel and open window.

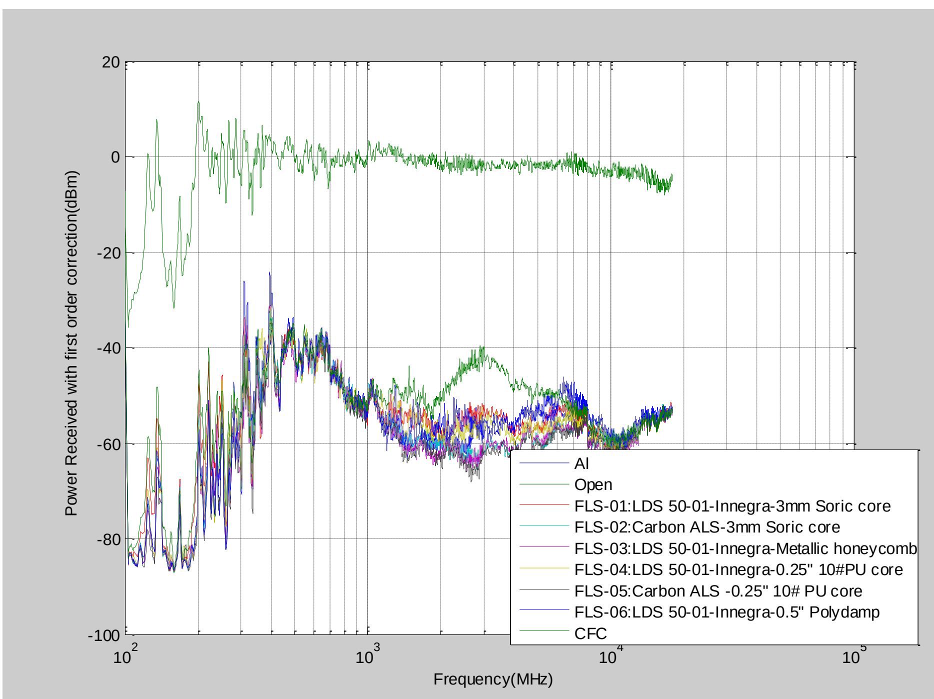


Figure 166: Shielding effectiveness of all panels with base substrate panel compared to an Al panel and open window.

Figure 167 shows the shielding effectiveness of all panels as compared to Aluminum and CFC. The shielding effectiveness of the Al panel should be the lower bound of all the panels at all frequencies; however, due to the limitations of the setup the performance of the panels can be better evaluated in the range of 700MHz to 2 GHz. Figure 168 shows the shielding effectiveness of the old CFC (7 layers of uni-directional with all orientation) and with the new CFC panel (2 outer layers of plain weave with 5 inner layers of unidirectional weave). In the range of interest (700MHz to 2 GHz) the performance of the new CFC was marginally better than the old CFC.

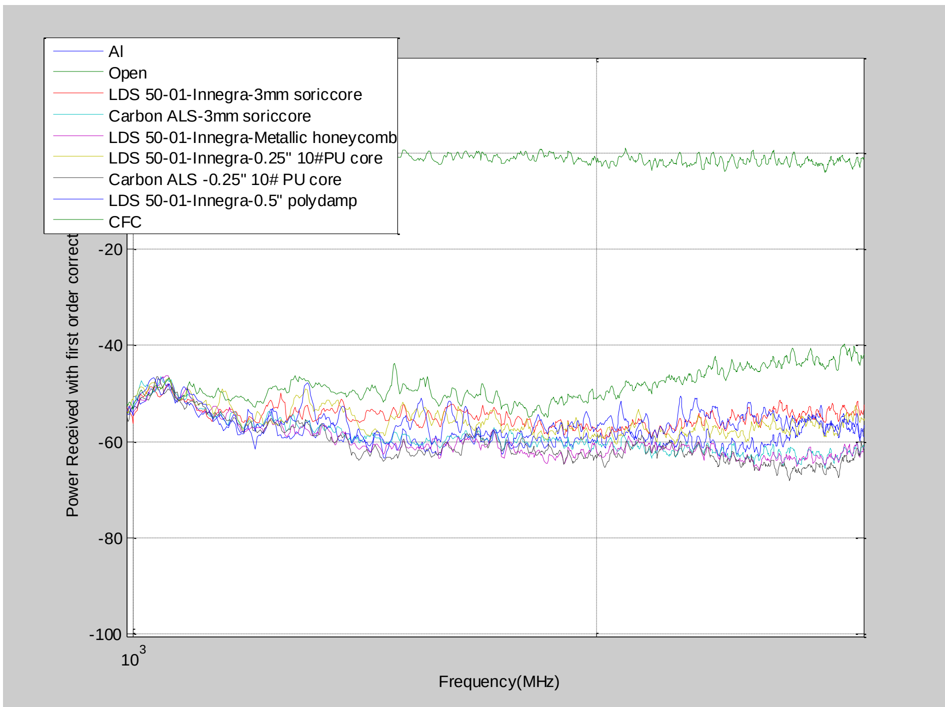


Figure 167: Shielding effectiveness of all panels from 700MHz to 2 GHz with base substrate panel compared to an Al panel and open window.

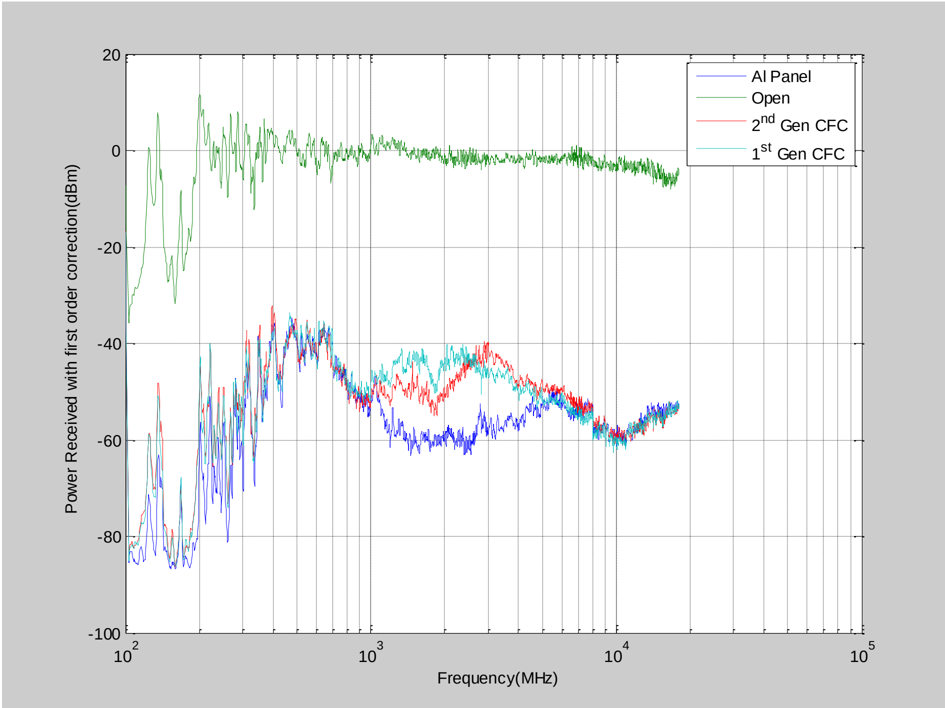


Figure 168: Shielding effectiveness of new base panel CFC new compared with the old base panel

8.3.3 Indirect Effects of Lightning

The panels were evaluated for possible effects of indirect effects of lightning coupling factors into a known "standard" wire bundle, based on Section 22 of RTCA DO-160G for open circuit voltage (Voc) and closed circuit current (Isc) for a standard cable bundle using generic waveform. The test setup and test procedure was identical to that used for the first-generation panels.

By looking at the waveform's rate of rise and decay, as well as the amplitude of both the voltage and current, it is possible to infer panel characteristics which may be otherwise difficult to measure directly. Inductance and capacitance of the panel, for example, are difficult to measure directly, but have a large impact on the wave shape. By comparing to baseline panels such as aluminum and CFC, it is possible to predict which transient waveforms would be seen during a lightning strike.

All the waveforms were tested to current level 3 with a peak equal to 616 A (Figure 169), and with the impedance of the panels the voltage (Figure 170) was tested to 800 V. This is the same as the first-generation panel testing.

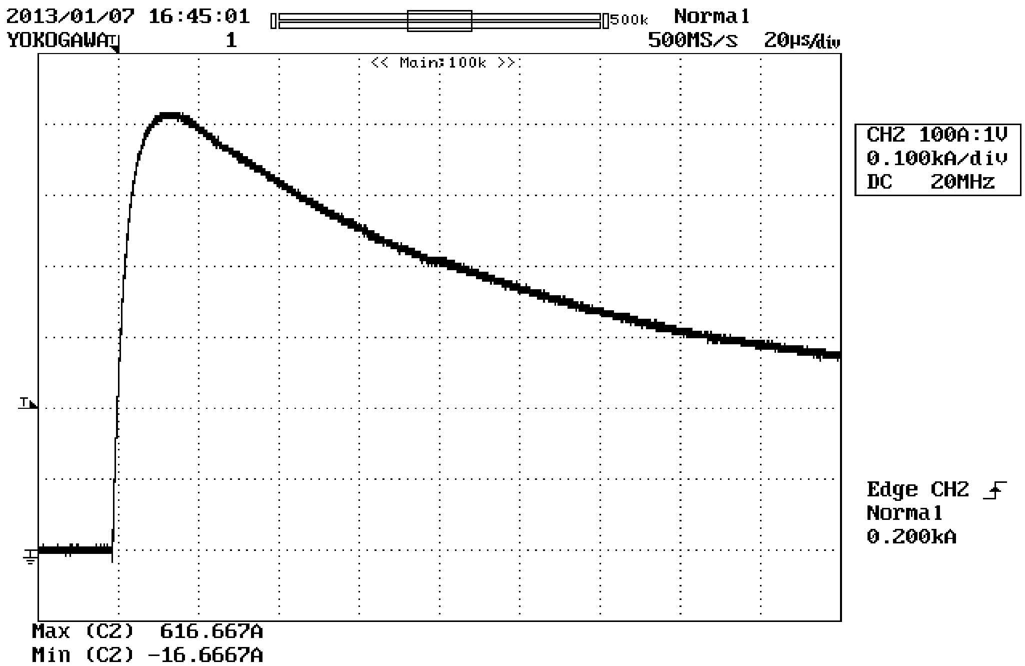


Figure 169: Current calibration oscillogram input waveform with 616 A.

Figure 170: Voltage calibration oscillogram waveform with 800 V.

The data collected for the six test articles and bare substrate panels are shown in Appendix K – Second-Generation Indirect Effects Test Data. The data is collected and summarized in Table 91 which shows results for different lightning strike protection materials for maximum peak current, maximum peak voltage and resistance between the bulkheads. These measurements were used to attempt to make a relative comparison of the important waveform parameters between the various materials.

Table 91 - Panel Details with Peak Current and Voltage

Panel ID	Panel details with Lightning Strike Material	Current (A)	Voltage (V)	Resistance (m Ω)
Al	Aluminum	622.5	808	
CFC	CFC	247.5	18	43.5
FLS-1	LDS 50-01-Innegra-3mm Soric core	460	20	11
FLS-2	Carbon ALS-3mm Soric core	420.5	20	30.6
FLS-3	LDS 50-01-Innegra-Metallic honeycomb	443.5	19.5	10.3
FLS-4	LDS 50-01-Innegra-0.25" 10 pcfPU core	464	21	12.2
FLS-5	Carbon ALS -0.25" 10 pcf PU core	420	19	40.3
FLS-6	LDS 50-01-Innegra-0.5" Polydamp	466	20.5	9.3

Table 93 summarizes panel performance with respect to wave shape distortion which may be seen during a lightning strike. When lightning attaches to a metal aircraft, the primary means of propagation is through the outer structure of the fuselage itself. The magnetic field created during this rapid current change can then induce a voltage (and subsequent current) on wire bundles installed inside the aircraft. In addition, the impedance between the entry and exit points of the lightning strike can create a potential difference seen between different sections of the aircraft. This potential difference will then generate a voltage between the two ends of a wire which is terminated at both ends and induce a current. Historically, the primary means of lightning induced transients on wire bundles for metal aircraft has been through magnetic field coupling. As the resistance of the airframe increases (e.g., beginning to install more composite material), the transient source seen on wire bundles begins to shift from magnetic field coupling to potential difference coupling.

Table 92 for current and **Error! Reference source not found.** for voltage were obtained by digitizing measured signals of closed circuit current and open circuit voltage on the cable bundle. A Matlab script was written to pick the 10% time, 50% percent time and max time and amplitude. In the case of 10% time, due to the sharp rise it was difficult to sample digitized points and hence 10% time was predicted based on a linear curve between the triggered start to maximum amplitude in the software. The ratio columns gives the ratios (~10%) and (~50%) with respect to maximum peak amplitude. Peak voltage varied from 18V to 21V for all materials.

Table 92 - Characteristics of Current Waveforms

Panel	Lightning protection material	Time for 10% (μs)	Amplitude at 10% (A)	Time at max (μs)	Max peak (A)	Time at 50% (μs)	Amplitude 50% (A)
Al	Aluminum	0.00	61.93	11.99	618.09	125.84	339.83
CFC	None	0.00	25.39	4.60	246.21	12.52	132.49
FLS-1	LDS 50-01-Innegra-3mm Soric core	0.37	47.94	11.48	451.58	54.27	247.01
FLS-2	Carbon ALS-3mm Soric core	0.10	40.06	9.45	417.33	36.73	228.14
FLS-3	LDS 50-01-Innegra-Metallic honeycomb	0.43	41.12	11.29	450.28	53.25	246.87
FLS-4	LDS 50-01-Innegra-0.25" 10 pcfPU core	0.41	47.85	9.66	458.51	56.80	245.95
FLS-5	Carbon ALS - 0.25" 10 pcf PU core	0.75	41.40	7.53	414.05	35.86	226.17
FLS-6	LDS 50-01-Innegra-0.5" Polydamp	0.10	40.91	11.28	448.56	58.71	244.44

Table 93 - Characteristics of Voltage Waveforms

Panel	Lightning protection material	Time for 10% (μs)	Amplitude at 10% (V)	Time at max (μs)	Max peak (V)	Time at 50% (μs)	Amplitude 50% (V)
Al	Aluminum	0.00	78.10	0.04	780.97	1.92	418.86
Al	Aluminum	0.00	81.33	0.04	813.32	1.87	437.08
CFC	CFC	0.48	1.07	4.80	10.69	11.62	5.58
FLS-1	LDS 50-01-Innegra-3mm Soric core	1.06	2.03	10.59	20.26	52.94	10.96
FLS-2	Carbon ALS-3mm Soric core	0.83	1.87	8.30	18.70	35.08	9.82
FLS-3	LDS 50-01-Innegra-Metallic honeycomb	1.53	2.02	15.32	20.22	50.16	10.77
FLS-4	LDS 50-01-Innegra-0.25" 10 pcfPU core	1.01	2.08	10.05	20.82	50.14	11.42
FLS-5	Carbon ALS - 0.25" 10 pcf PU core	0.02	1.66	7.67	17.79	32.56	9.73
FLS-6	LDS 50-01-Innegra-0.5" Polydamp	0.13	1.98	7.71	19.78	52.72	10.66

The characteristics of the magnetic field coupled waveforms and the potential difference coupling while installed on an aircraft can be summarized as follows: magnetic field coupling has a higher rate of change, but shorter duration; potential difference coupling has a slower rate of change, but longer duration. Depending on the system or box of interest, one could present a more severe threat than the other (higher rate of change versus more average power). Because different systems may be susceptible to different threats in different ways, it is not the intent of this discussion to declare one installation “worst case” or one a “better performer.” It is instead to understand how the material might behave during a lightning strike.

8.3.4 Direct Effects of Lightning

Similar to the first-generation panels, the six second-generation panels were struck twice on each panel using current component D (APR 5412A) with an amplitude of 100 kA on the protective skin side of the composite panel. Additionally, two of these panels (FLS-1 and FLS-6) were struck a third time with 200kA on the lightning strike protection material without the Integument film since the film was displaced due to prior strikes. The panels were tested according to applicable sections of SAE ARP5416.

Testing was again conducted at DNB Engineering in Fullerton, California. Their complete test report, including pictures and test data, is presented in Appendix L – Direct Effects Test Data and Pictures (DNB). The Cessna pictures are shown on the following pages.

Figure 171 and Figure 172 show a sample of pretest setup of FLS-1 with labels of the various components shown in Figure 171.

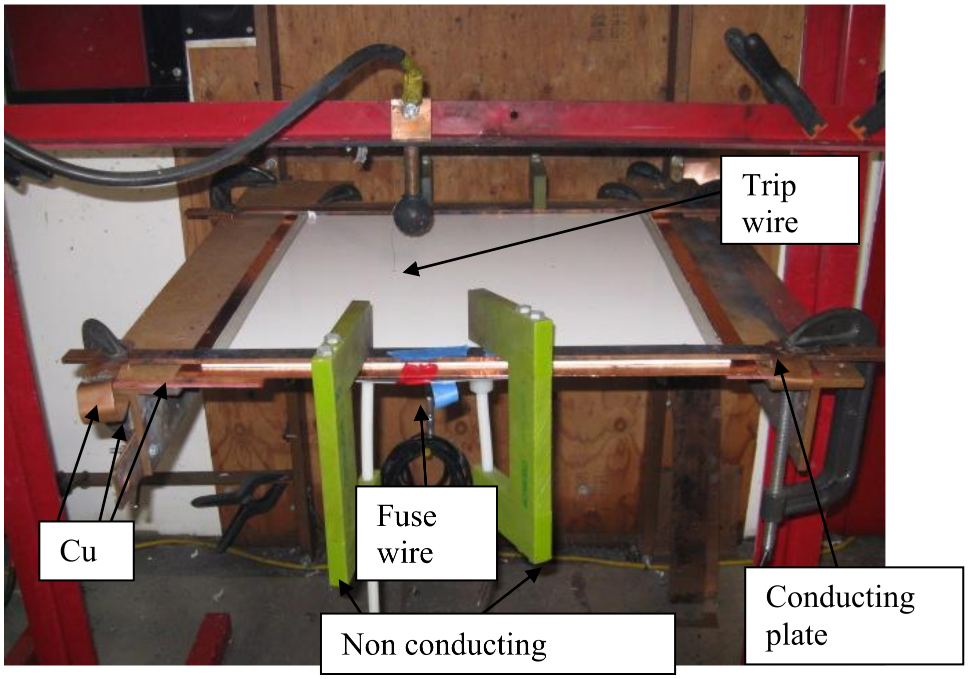


Figure 171: Panel FLS-1 pre strike #1 (setup).

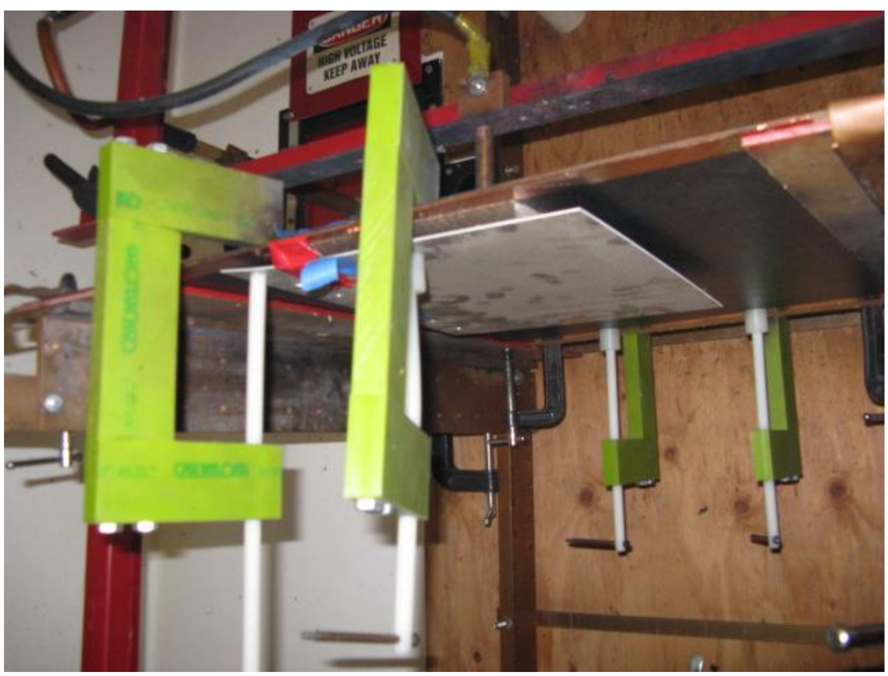


Figure 172: Panel FLS-1 pre strike #1 (setup).

Figure 173 shows FLS-1 after the first strike while Figure 174 shows the panel prior to the second strike. What is important about Figure 174 is the placement of the trip wire relative to the first strike – it is located on the other side of the panel. In addition to changing sides, the trip wire is positioned to try to be away from the panel edge by six inches and to be centered between the overlapped layers of material.

Figure 173: Panel FLS-1 post strike #1.

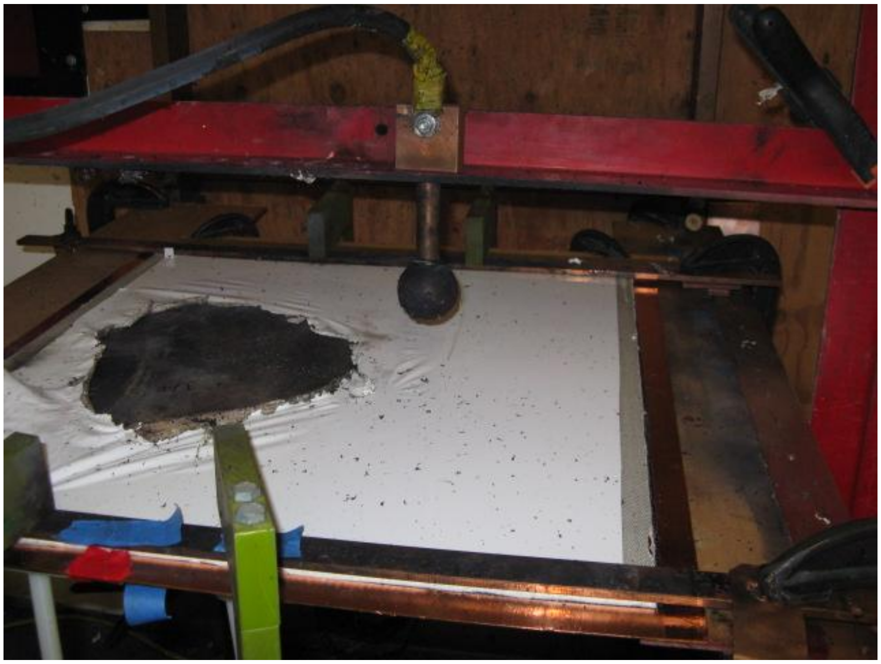


Figure 174: Panel FLS-1 pre strike #2 (setup).

Figure 175 shows FLS-1 after strikes 1 and 2. Figure 176 shows the panel before strike 3. The position of the trip wire has been moved to a spot which has not been struck before; the previous strikes have removed all of the Integument protective film.

Figure 175: Panel FLS-1 post strike #1 and #2.

Figure 176: Panel FLS-1 pre strike #3.

FLS-1 after all three strikes is shown still mounted in the test fixture in Figure 177. The front of the panel is shown in Figure 178, and the back of the panel is shown in Figure 179. The back of the panel has dots indicating the target lightning strike location for each of the three strikes. As mentioned previously, the goal was to stay six inches from the edges and away from the overlapped layers of material.

Figure 177: Panel FLS-1 post strike #1, #2, and #3.

Figure 178: Front of panel FLS-1 post strike #1, #2, and #3.

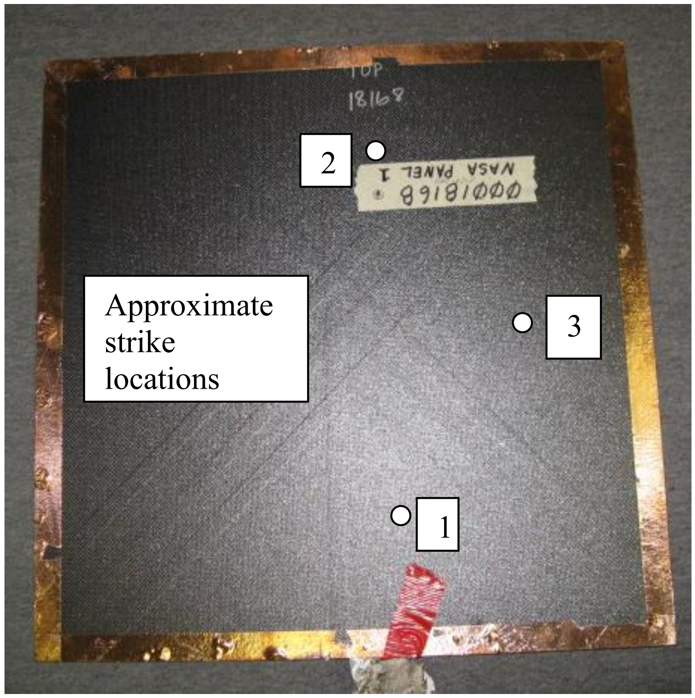


Figure 179: Back of panel FLS-1 post strike #1, #2, and #3.

The same sequence of figures is presented in Figure 180 through Figure 187 for FLS-2, in Figure 188 through Figure 199 for FLS-3, in Figure 200 through Figure 206 for FLS-4, in Figure 207 through Figure 214 for panel FLS-5, and in Figure 215 through Figure 224 for FLS-6. Panels FLS-2, FLS-3, FLS-4, and FLS-5 each had two strikes. Panel FLS-6 had three strikes.

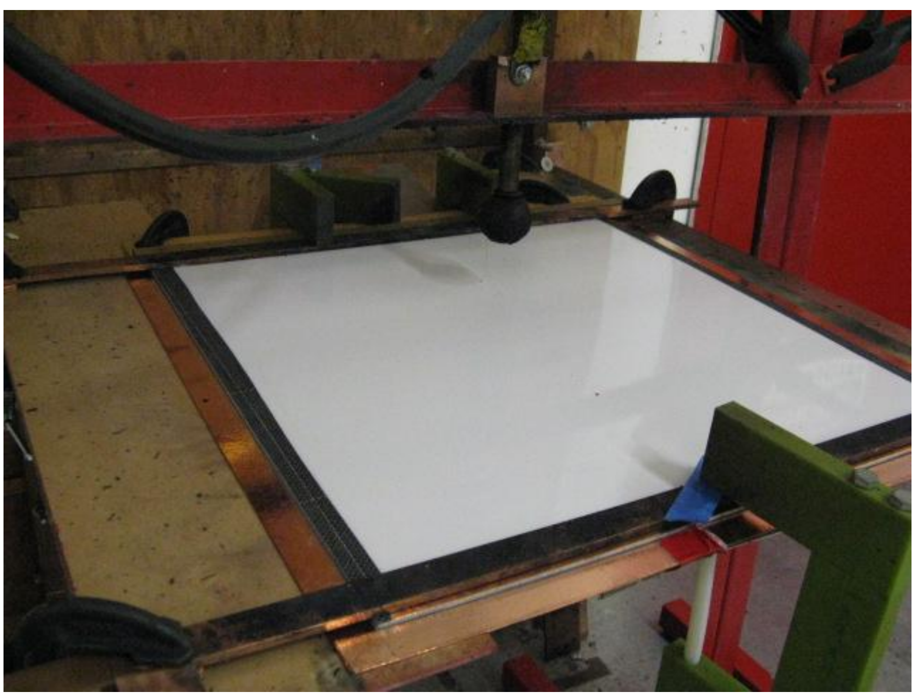


Figure 180: Panel FLS-2 pre strike #1 (setup).

Figure 181: Panel FLS-2 pre strike #1 (setup).

Figure 182: Panel FLS-2 post strike #1.

Figure 183: Panel FLS-2 pre strike #2 (setup).

Figure 184: Panel FLS-2 post strike #1 and #2.

Figure 185: Panel FLS-2 post strike #1 and #2.

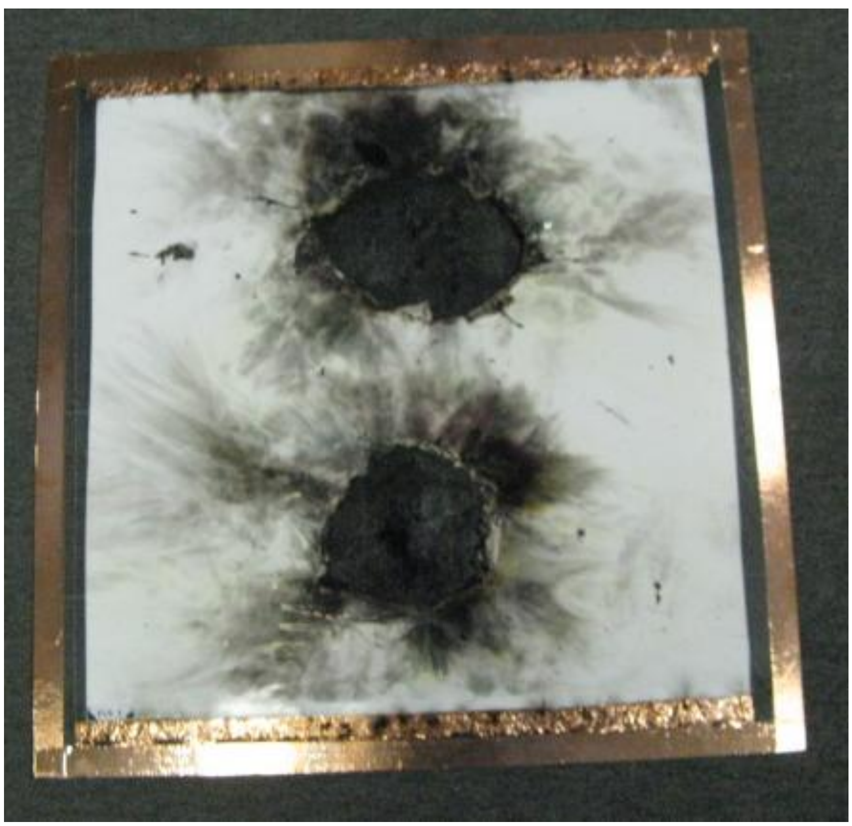


Figure 186: Front of panel FLS-2 post strike #1 and #2.

Figure 187: Back of panel FLS-2 post strike #1 and #2.

Figure 188: Panel FLS-3 pre strike (setup).

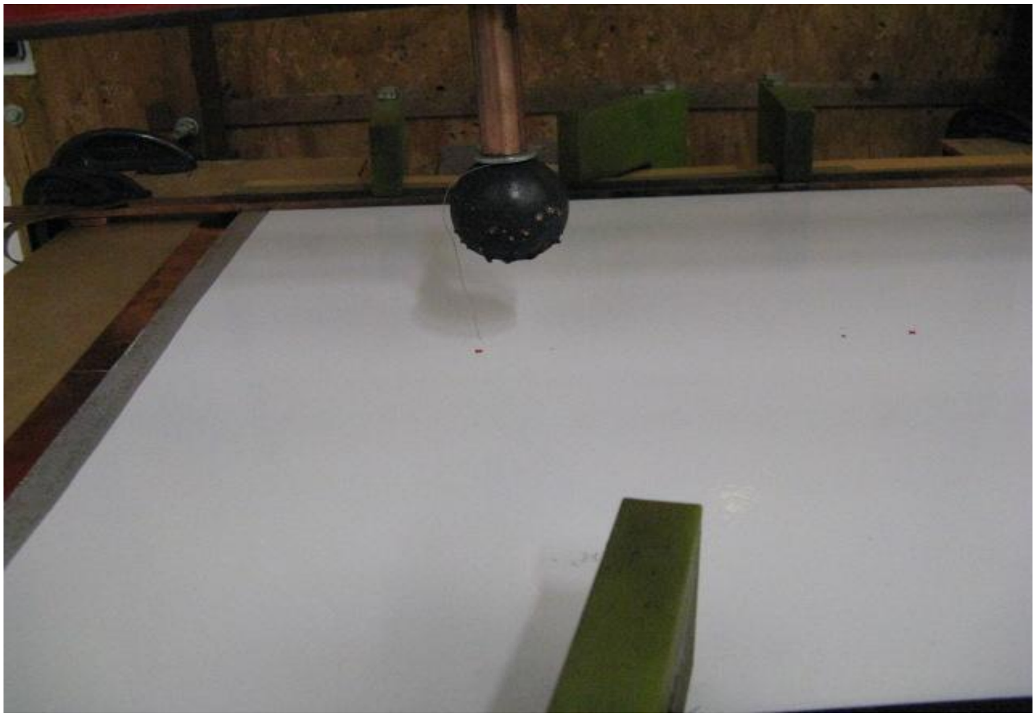


Figure 189: Panel FLS-3 pre strike (setup).

Figure 190: Panel FLS-3 pre strike (setup).

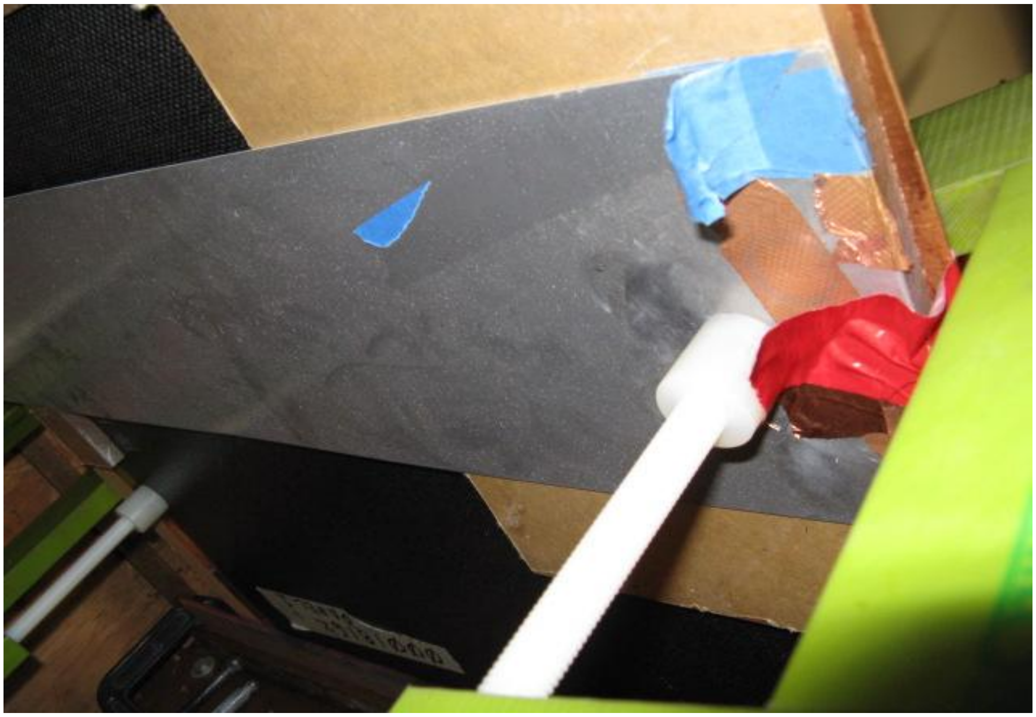


Figure 191: Panel FLS-3 pre strike (setup).

Figure 192: Panel FLS-3 post strike #1.

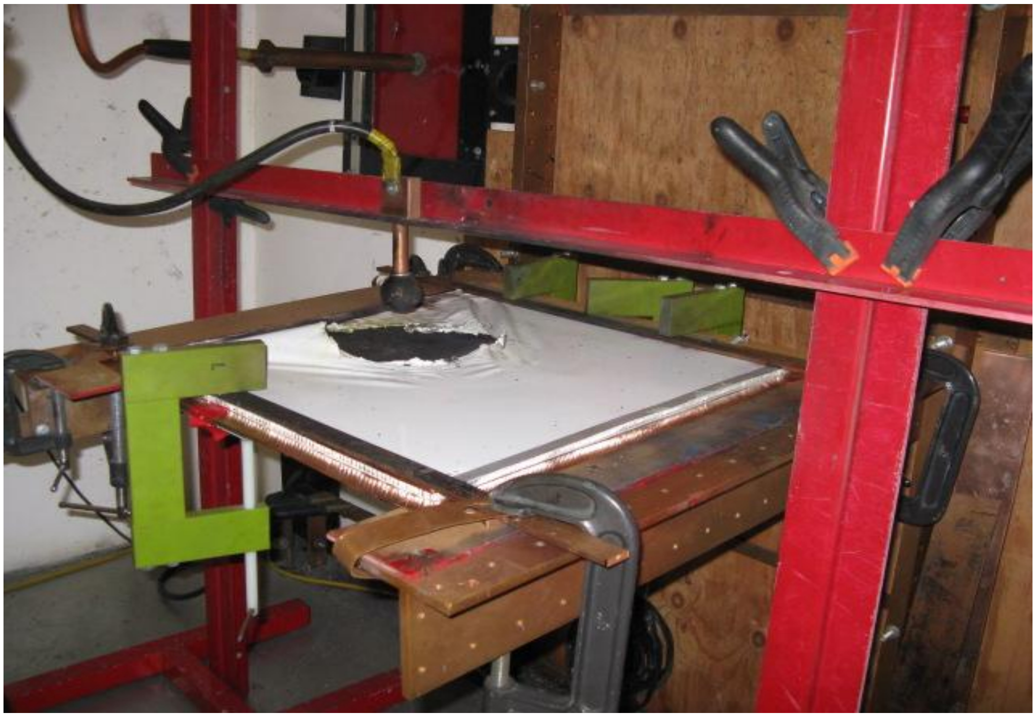


Figure 193: Panel FLS-3 post strike #1.

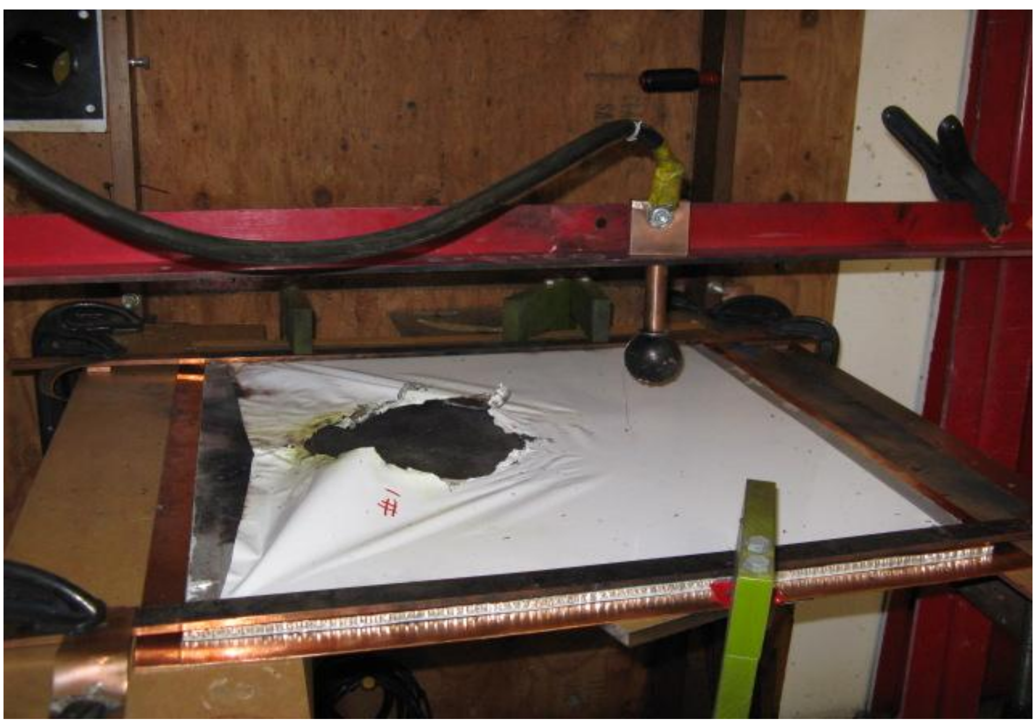


Figure 194: Panel FLS-3 pre strike #2 (setup).

Figure 195: Panel LS-3 pre strike #2 (setup).

Figure 196: Panel FLS-3 post strike #1 and #2.

Figure 197: Panel FLS-3 post strike #1 and #2.

Figure 198: Front of panel FLS-3 post strike #1 and #2.

Figure 199: Back of panel FLS-3 post strike #1 and #2.

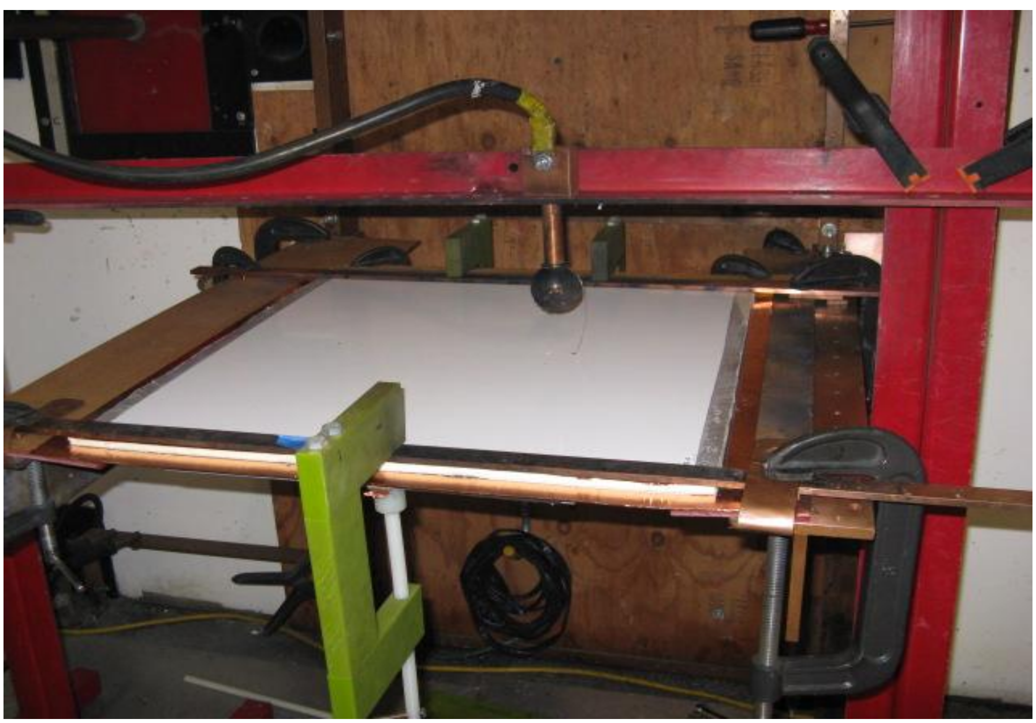


Figure 200: Panel FLS-4 pre strike #1 (setup).

Figure 201: Panel FLS-4 pre strike #1 (setup).

Figure 202: Panel FLS-4 post strike #1.

Figure 203: Panel FLS-4 pre strike #2 (setup).

Figure 204: Panel FLS-4 post strike #1 and #2.

Figure 205 - Front of panel FLS-4 post strike #1 and #2.

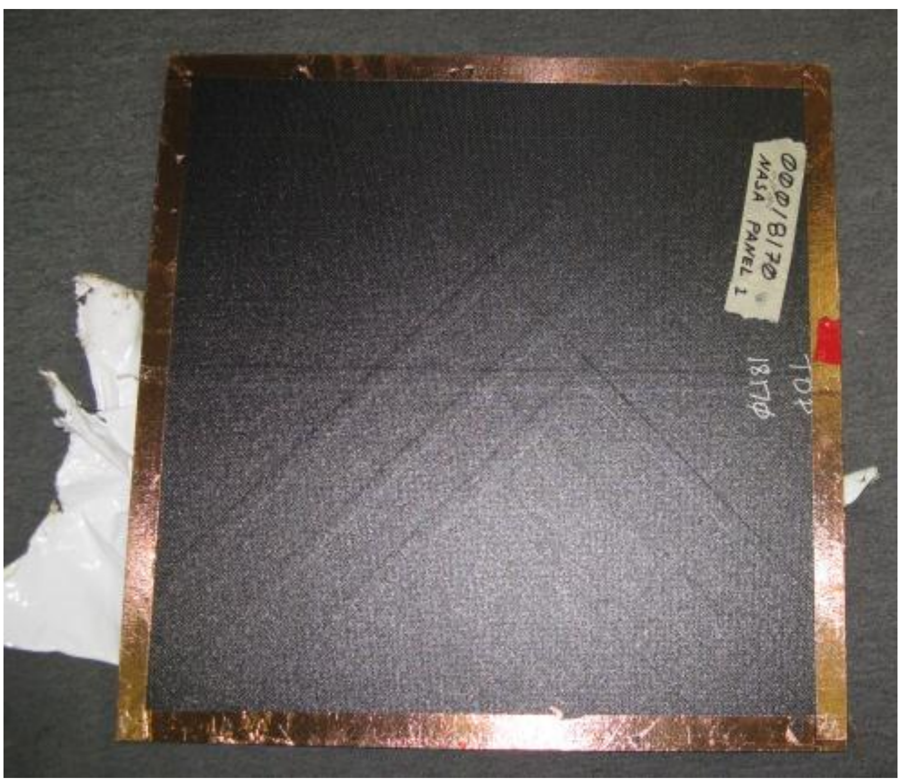


Figure 206: Back of panel FLS-4 post strike #1 and #2.

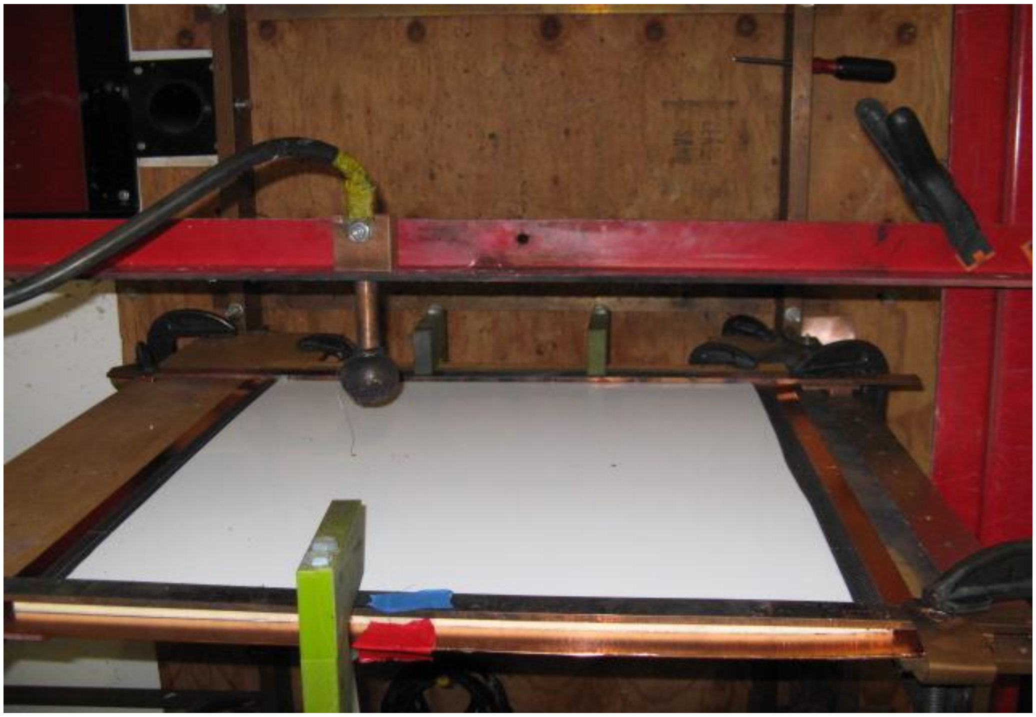


Figure 207: Panel FLS-5 pre strike #1(setup).

Figure 208: Panel FLS-5 pre strike #1(setup).

Figure 209: Panel FLS-5 post strike #1.

Figure 210: Panel FLS-5 post strike #1.

Figure 211: Panel FLS-5 pre strike #2 (setup).

Figure 212: Panel FLS-5 post strike #1 and #2.

Figure 213: Front of panel FLS-5 post strike #1 and #2.

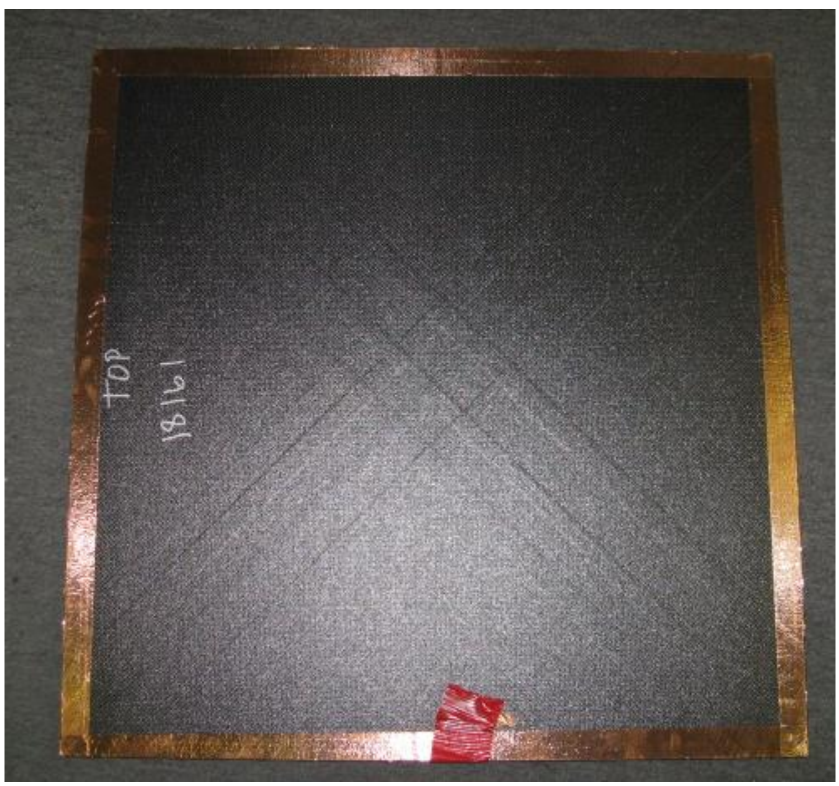


Figure 214: Back of panel FLS-5 post strike #1 and #2.

Figure 215: Panel FLS-6 pre strike #1(setup).

Figure 216: Panel FLS-6 post strike #1.

Figure 217: Panel FLS-6 pre strike #2 (setup).

Figure 218: Panel FLS-6 post strike #1 and #2.

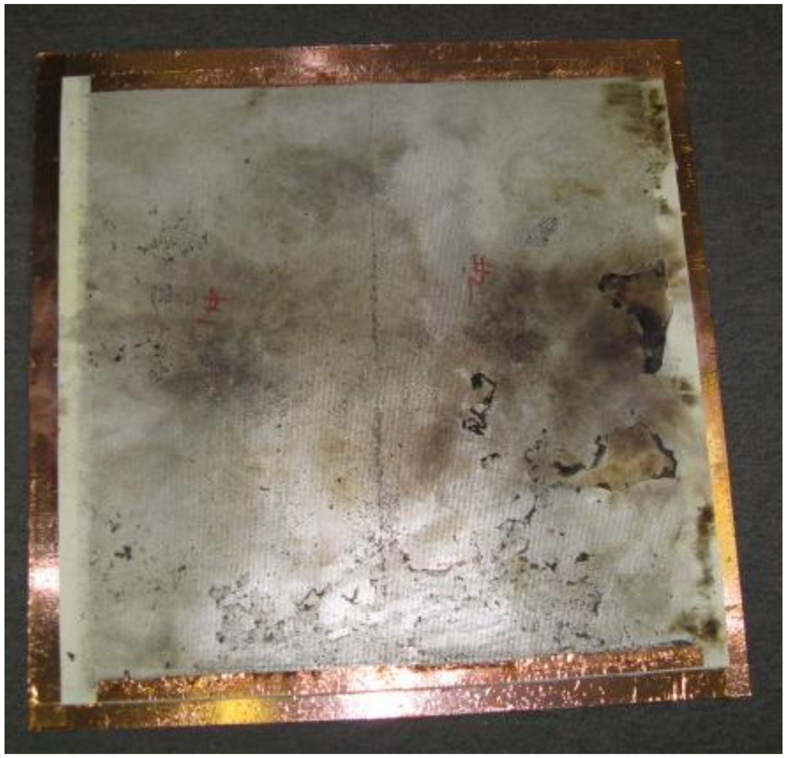


Figure 219: Front of panel FLS-6 post strike #1 and #2.

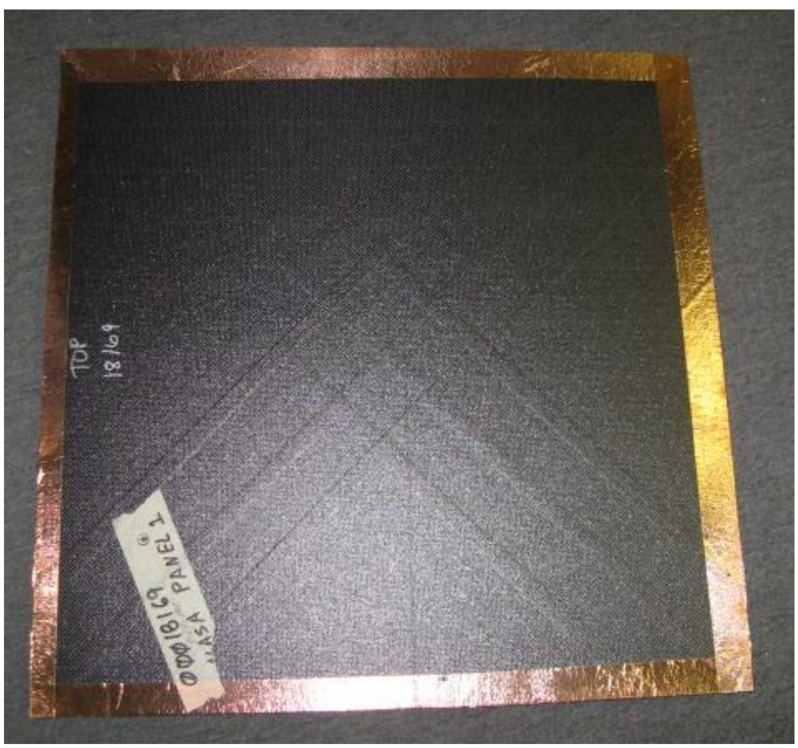


Figure 220: Back of panel FLS-6 post strike #1 and #2.

Figure 221: Panel FLS-6 pre strike #3 (setup).

Figure 222: Panel FLS-6 post strike #1, #2, and #3.

Figure 223: Front of panel FLS-6 post strike #1, #2, and #3.

Figure 224: Back of panel FLS-6 post strike #1, #2, and #3.

The convention for damage on the panel's inner hole is a hole in the base substrate panel, and outer hole is a hole in the outer layers of the protective skin. Inner delamination (debond and delamination seen in the base substrate panel) and outer delamination (debond seen in the protective skin) were measured with thermography and tap test, respectively. Damage sizing was performed for the base substrate (backside) using thermography. The thermography report for all base substrate panels and lightning strike and impact test articles is provided in the document Appendix H - Thermography Report.

Table 94 shows post-strike damage on the panels. All of the lightning strike panels were inspected from the front side. Tap tests were done to get an approximate measurement of debond in the core location. Due to the fact that these panels had lightning mesh and charred material followed by a tempera paint surface preparation (used for preparing panel for thermography), a reliable infrared thermography inspection of front-side protective skin damage could not be achieved [Appendix J – Second-Generation Thermography Report]. The inner delamination measurement presented is the equivalent diameter of a circle with the area found from the thermography inspection.

Table 94 - Damage and Delamination for All Panels (Post Lightning Strike)

Panel number	Strike	Inner Hole (in)	Inner Delamination (in)	Inner damage (in)	Outer Hole (in)	Outer Delamination (in)	Current (k A)
FLS-1	1	0	0	0	0	0	100
FLS-1	2	0	0	0	0	0	100
FLS-1	3	0	0	0	0	0	200
FLS-2	1	0	0	0	0.564	5.11	100
FLS-2	2	0	0	0	0	6.694/0.2*	100
FLS-3	1	0	0	0	0	0	100
FLS-3	2	0	0	0	0	0	100
FLS-4	1	0	0	0	0	0	100
FLS-4	2	0	0	0	0	0	100
FLS-5	1	0	0	0	1.14	3.1/0.9*	100
FLS-5	2	0	0	0	0	4.13/0.25*	100
FLS-6	1	0	0	0	0	0	100
FLS-6	2	0	1.15	0	0	0	100
FLS-6	3	0	0	0	0	0	200

*Broken Fiber in the CFC

All of the panels passed visual inspection after direct strike testing for both the 100 and 200 kA strikes. Thermographic inspection showed that all panels except FLS-6 passed direct strike testing.

Only panel FLS-6 did not pass the "no inner delamination" requirement with a 1.15 in^2 debond (see Table 94); that failure was located in the area of the second 100 kA strike. No delamination was detected in the area of the 200 kA strike. Unfortunately, it was not possible to perform the thermographic inspection at DNB Engineering after each strike. All strikes were made, and the panels were returned to Cessna for inspection. Figure 225 shows the pre and post strike thermography for the base substrate panel used in FLS-6. Some delamination was present in the overlap areas before the strike as shown in the red ellipses on the left image. The proximity of strike #2 to an already delaminated area may have caused the delamination to change. The fact that strike #3, at twice the intensity of strikes #1 and #2, and in an area without prior delamination did not appear to cause delamination makes it difficult to eliminate the Polydamp Hydrophobic Melamine as a viable protective skin material.

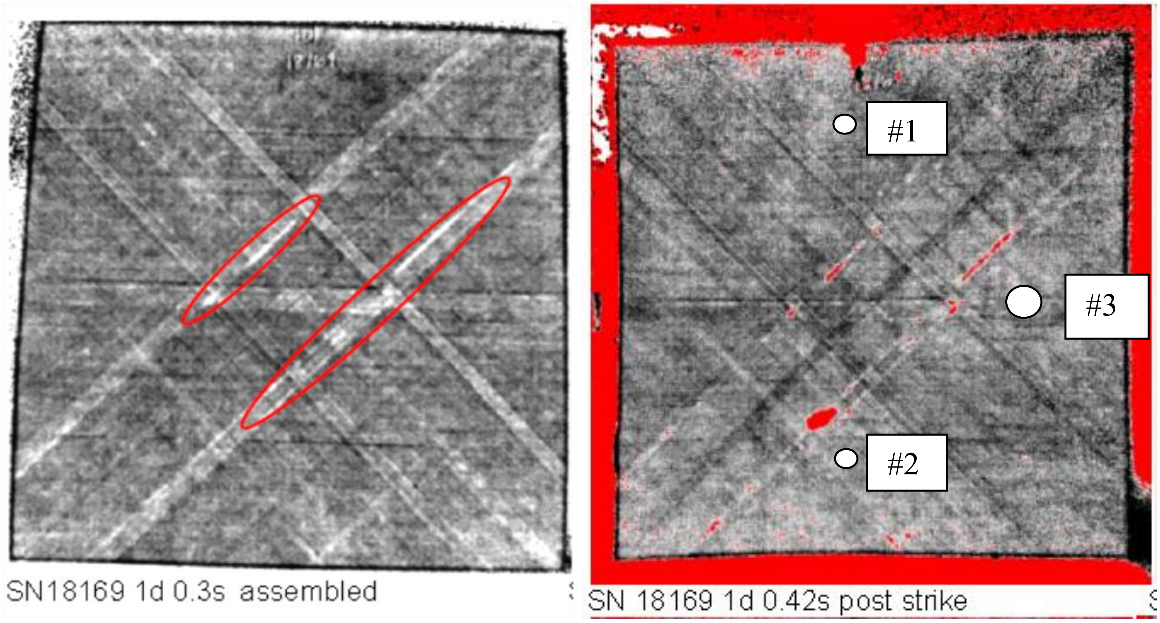


Figure 225: Pre and post strike thermographic images of base substrate panel for FLS-6.

8.4 Aesthetics and Smoothing

The purpose of this testing is to evaluate the second generation of STAR-C^2 protective skin test panels for aesthetics and smoothing. Testing for the second-generation panels was conducted in basically the same manner as for the first-generation panels although the base substrate panel design was modified from that used for the first-generation panels by removing the middle fastener size and the wire bundle simulations. The drawing for the second-generation modified base substrate panel is shown in Figure 226. The first-generation modified base substrate panel was shown in Figure 93. The material composition of the second-generation panels was described in Section 8.1.

In addition to the 24” x 24” test articles built specifically for aesthetics and smoothing testing (FAS-1 through FAS-6), visual inspection was also conducted for the 48” x 48” acoustics test articles (FAC-1 through FAC-6) to gather additional feedback from how the materials performed on the larger panel sizes. The specific combinations of material for the acoustic test articles were the same as for the Aesthetic and Smoothing panels. Data graphs, pictures, and test log scans are provided for each of these in the following subsections.

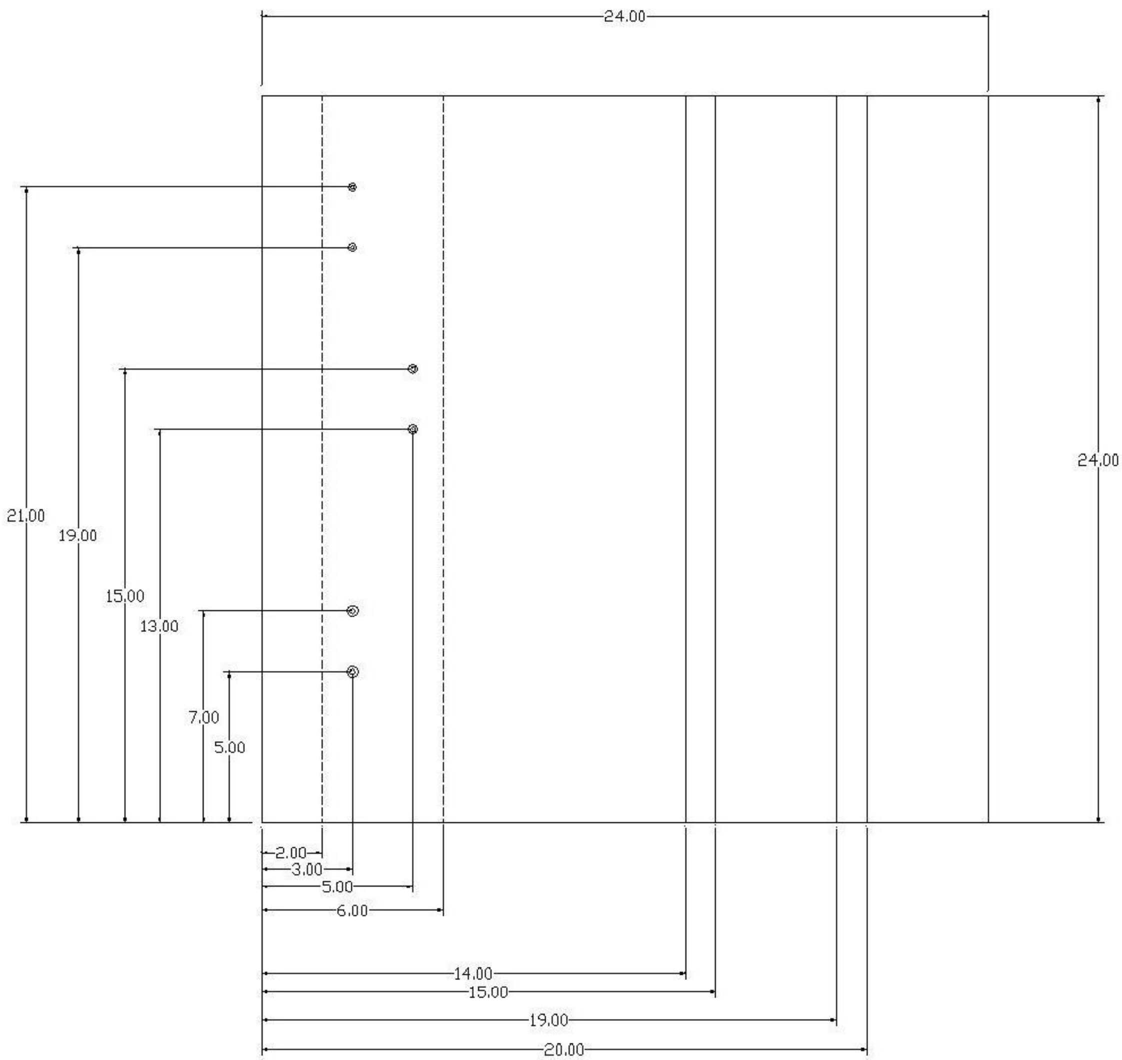


Figure 226: Base substrate for aesthetic and smoothing test panels showing fasteners and doublers.

8.4.1 Test Panel Assembly

8.4.1.1 *Aesthetics and Smoothing Panels*

The material combinations used for impact energy absorption, impact energy spreading, lightning strike protection and aesthetics and smoothing as listed in Table 80 were combined into single piece stack-ups prior to being applied to the modified base substrate panels. With the exception of the Polydamp based stack-up, these material stack-ups each included a layer of 3M 4950 VHB tape, which was used to adhere the stack-ups to the base substrates. The Polydamp was supplied with a layer of PSA applied by the supplier, which was used to adhere it to the base substrate.

Application of the stack-ups to the base substrates necessitated the use of the fixture fabricated for the first-generation panels to accommodate the geometric features which were created on the underside of the base panels, namely the fasteners and aluminum shim stock that was used to accommodate the grip length of the blind fasteners. This fixture, shown in Figure 227, was manufactured from a piece of medium

density fiberboard with a machined slot for the shim stock and additional holes in the required locations for the fasteners. The fixture allowed for the base panels to sit flat while the stack-ups were applied, as can be seen in Figure 228 and Figure 229.

In order to allow for consistent application of the stack-ups to the base substrate panels, the application roller created for the first-generation test articles was used. The roller, shown in Figure 230 and Figure 231, consisted of a 4" section of PVC pipe that was fitted with pressure fittings on either end. The pipe was filled with sand, tamped down, and refilled, until no more sand could be added. Water was then added to the sand, until saturation was achieved. The resulting application roller was approximately 30" in width and weighed 28.2 pounds.

Application of the stack-ups to the modified base substrates was accomplished by removing the separator paper from the VHB tape, placing the stack-up on top of the modified base substrate loaded in the application fixture, and rolling the application roller from right to left and then bottom to top, as shown in Figures 3 through 6. In this orientation, the roller was first rolled over the two aluminum doublers and then the flush and protruding head fasteners on the first pass. The second pass was made to ensure that the stack-up was applied with pressure in both directions.

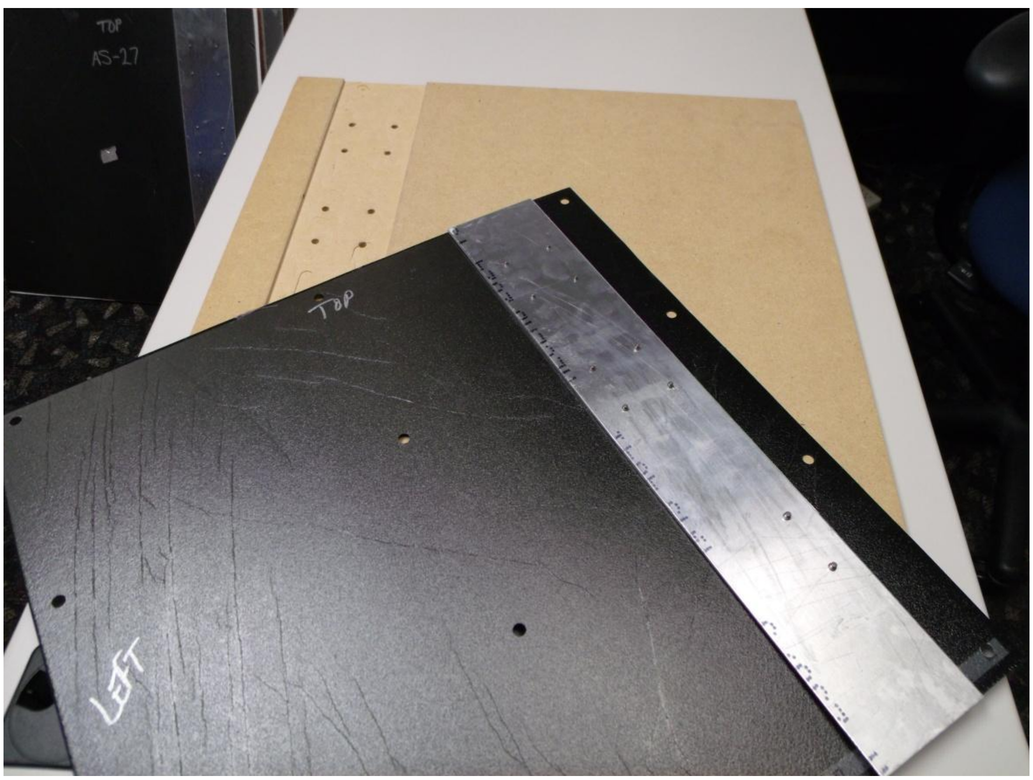


Figure 227: Aesthetic and smoothing base substrate panel holder.

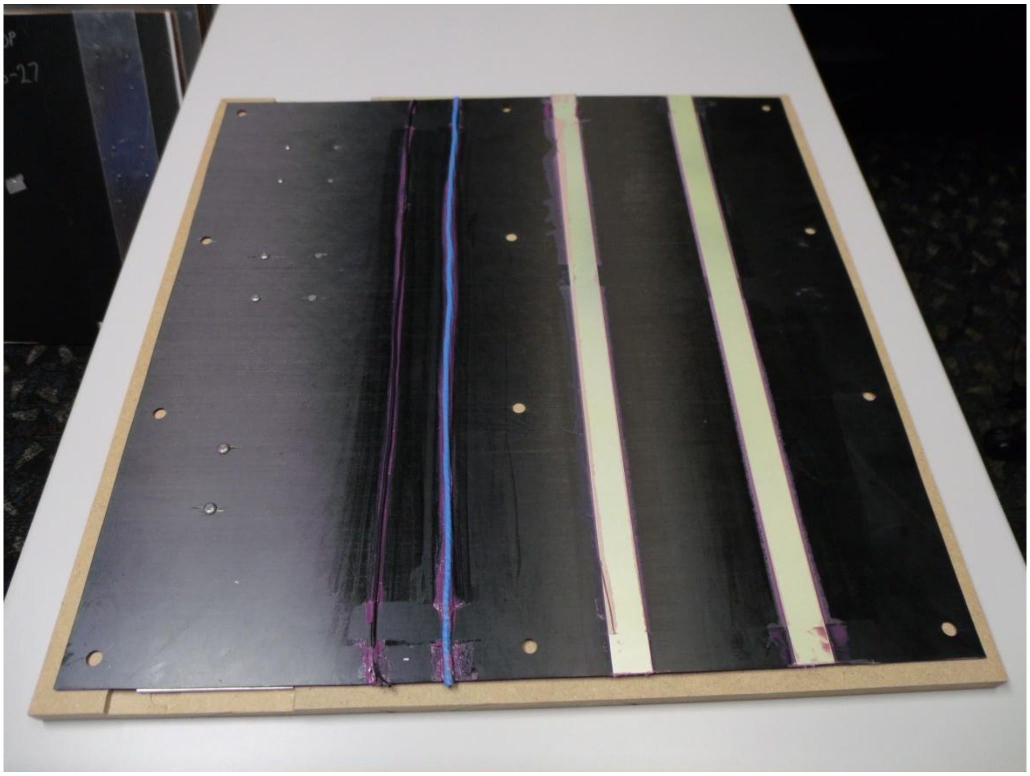


Figure 228: Aesthetic and smoothing base substrate loaded for stack-up application.

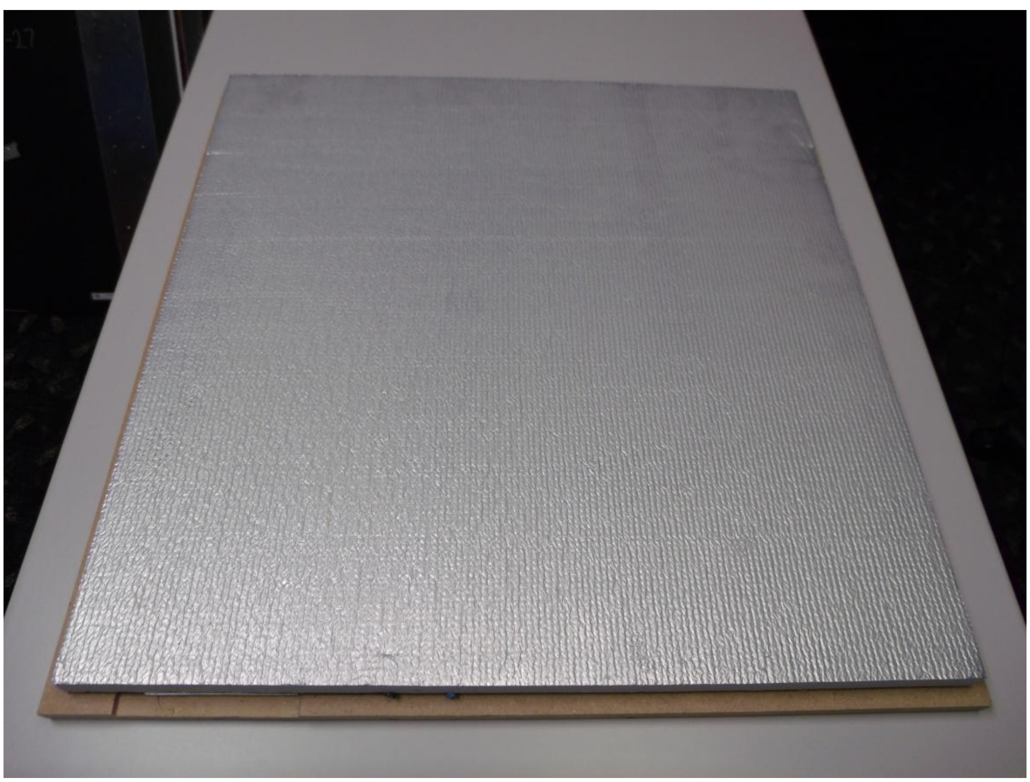


Figure 229: Stack-up applied to base substrate.

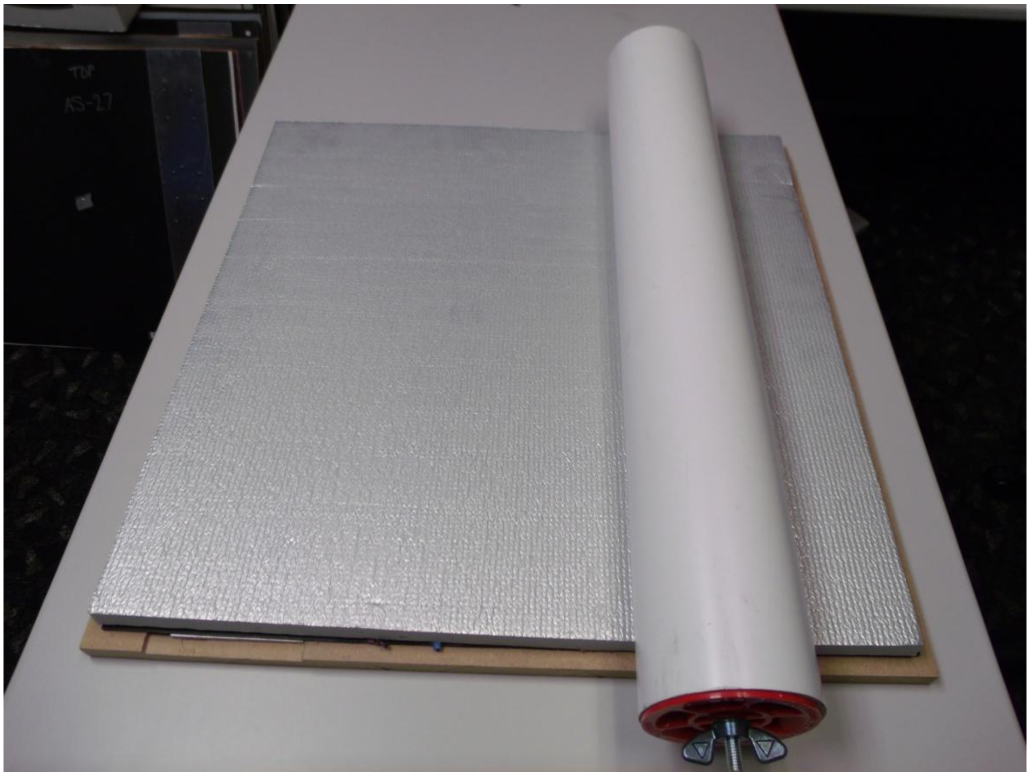


Figure 230: Application of stack-up with pressure roller, left to right.

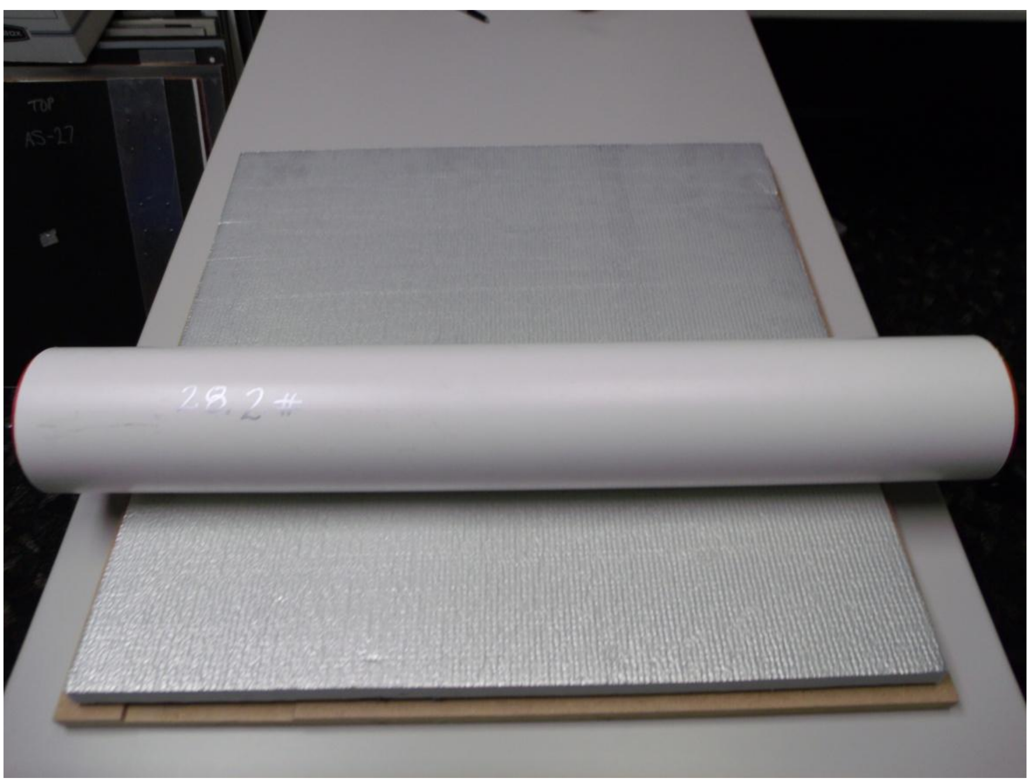


Figure 231: Application of stack-up with pressure roller, bottom to top.

8.4.1.2 ***Acoustic Panels***

The acoustic panel protective skins were manufactured in the same way as the aesthetics and smoothing protective skins. The tape was removed from the 3M 4950 VHB tape, and the protective skin was aligned with the base substrate panel and connected to the base substrate panel by hand. No special equipment was utilized. The acoustic test panels are 48" x 48."

8.4.2 Aesthetic and Smoothing Test Results

8.4.2.1 ***Aesthetics and Smoothing Panels***

In order to gain some useful data with which to analyze the effectiveness of the stack-ups for aesthetics and smoothing, notes from visual examinations of the panels were recorded, a number of physical measurements of the panels were taken, and photographs of the panels were captured. The photographs are shown in the following pages, and generally show a front view, an edge view, and a shadowed front view of the panel. The shadowed front view is a new technique when compared to the methods used for the first-generation panels report, and assists in showing some of the translation of underlying surface features to the outer surface of the panel. Additional photos were taken of specific local surface deviations or phenomenon that were of interest and are also presented here.

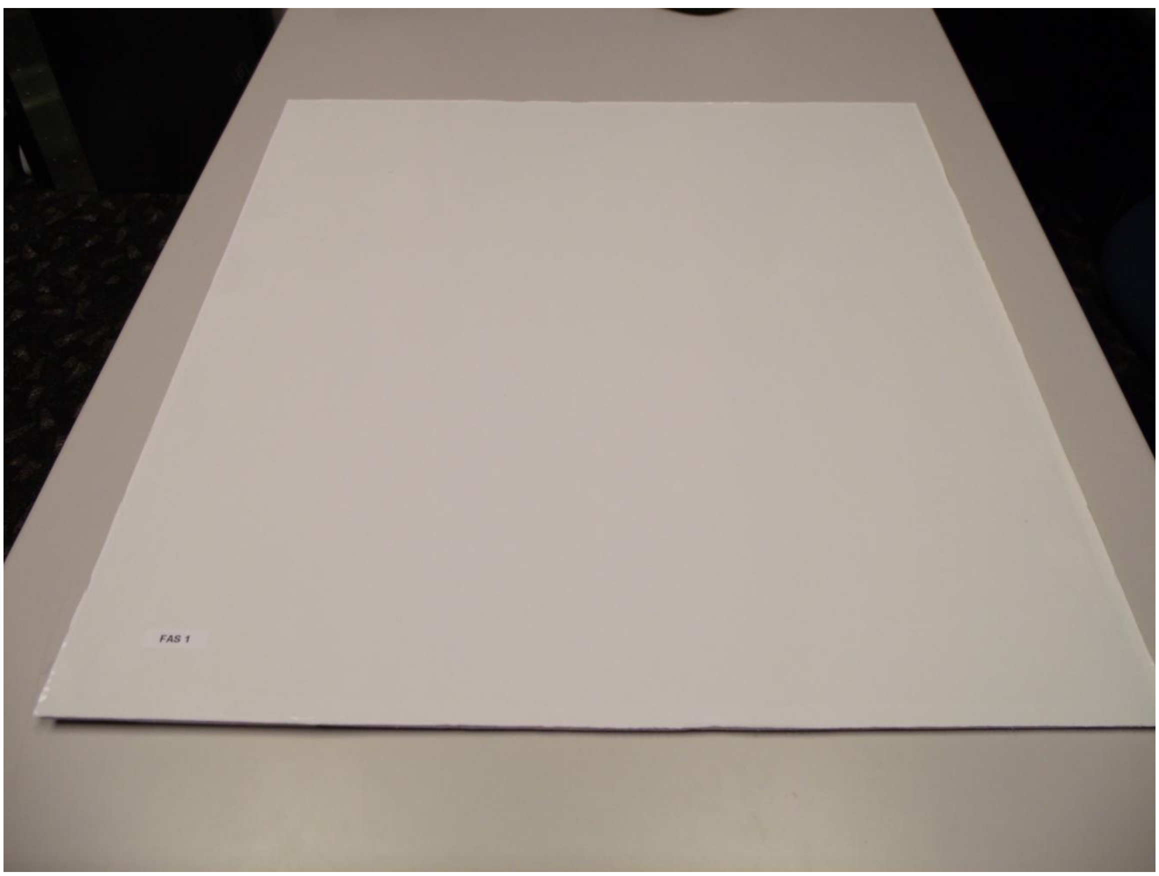


Figure 232: Panel FAS-1 front view.

Figure 233: Panel FAS-1 edge view.

Figure 234: Panel FAS-1 shaded front view.

Figure 235: Panel FAS-2 front view.

Figure 236: Panel FAS-2 edge view.

Figure 237: Panel FAS-2 Shaded Front View.

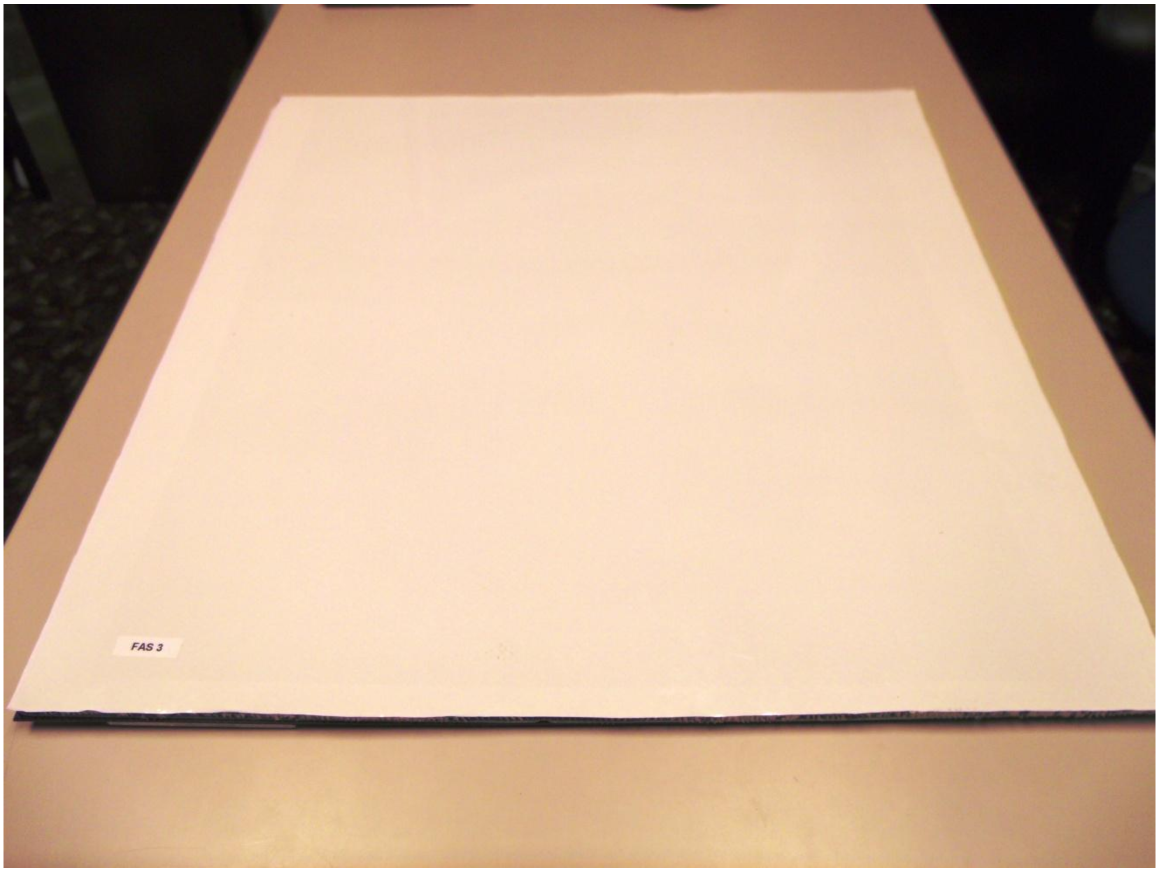


Figure 238: Panel FAS-3 front view.

Figure 239: Panel FAS-3 edge view.

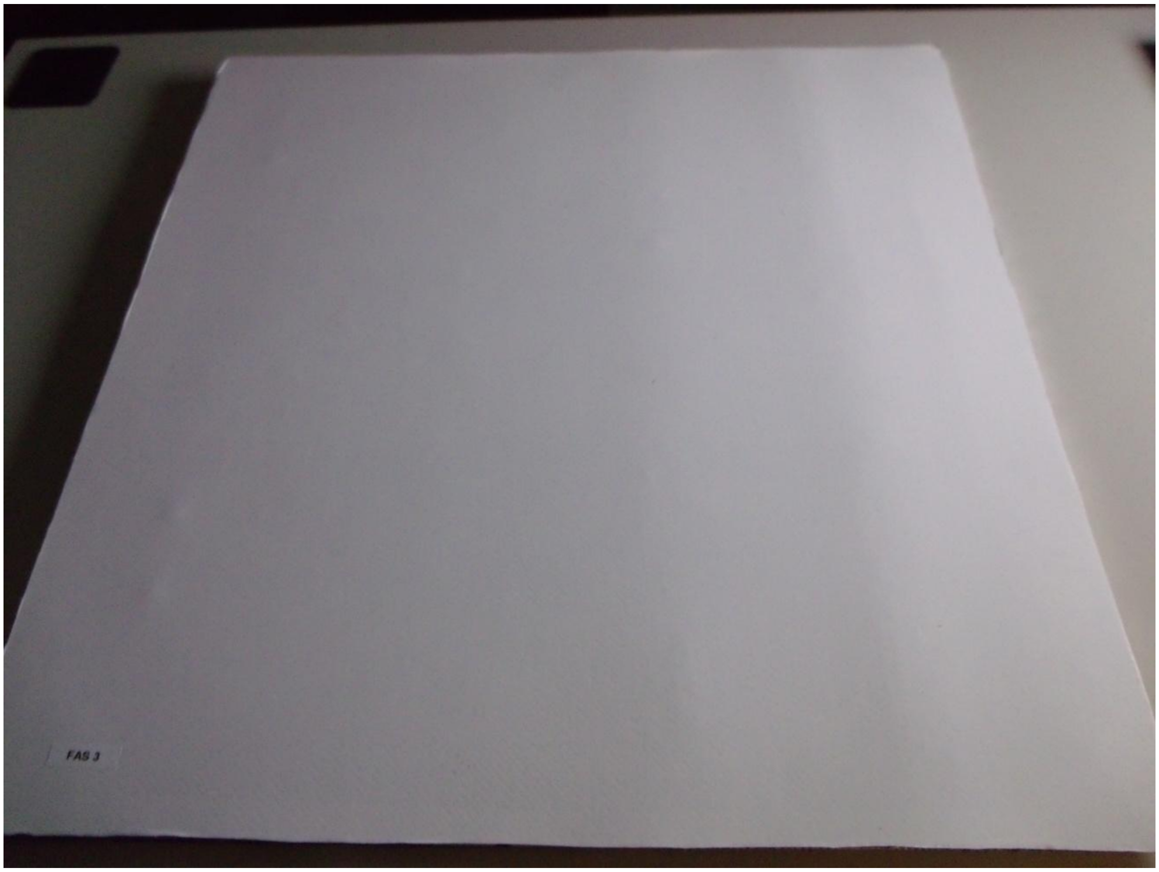


Figure 240: Panel FAS-3 shaded front view.

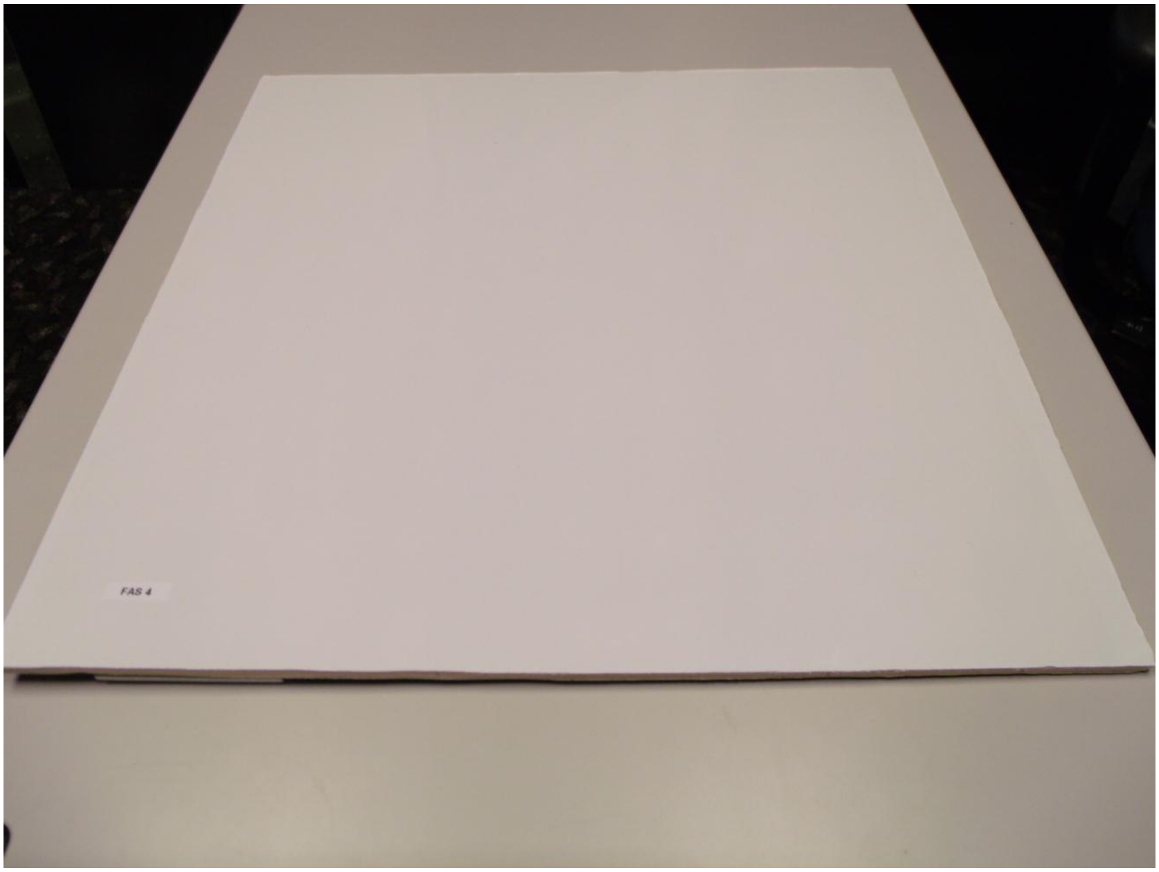


Figure 241: Panel FAS-4 front view.

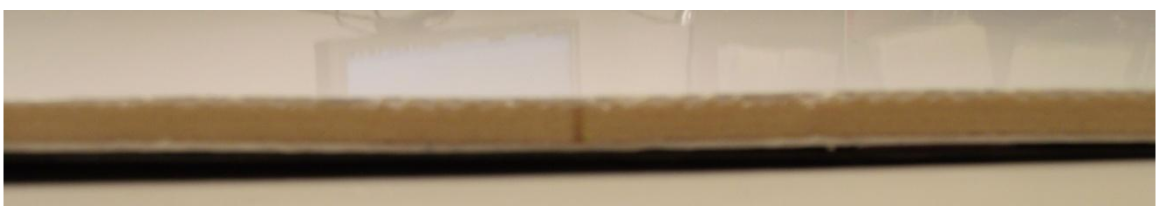


Figure 242: Panel FAS-4 edge view.

Figure 243: Panel FAS-4 shaded front view.

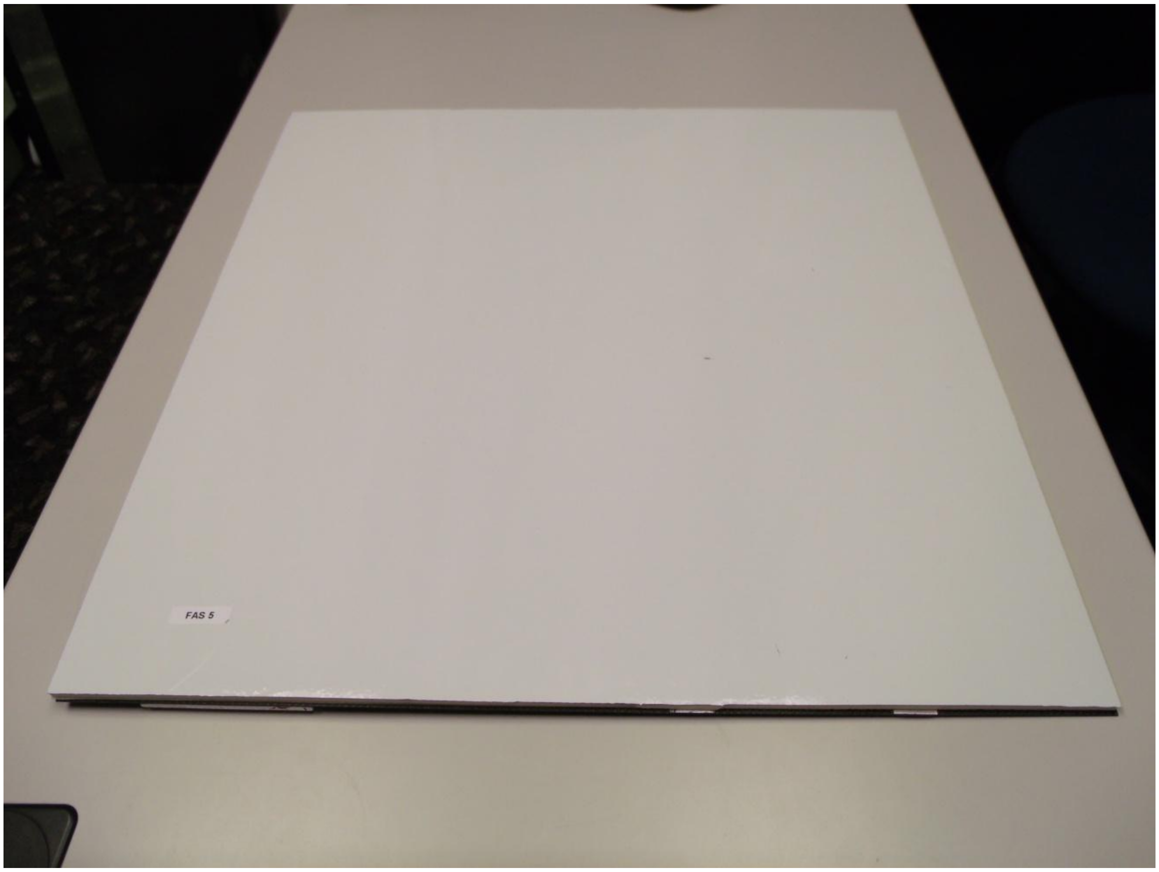


Figure 244: Panel FAS-5 front view.

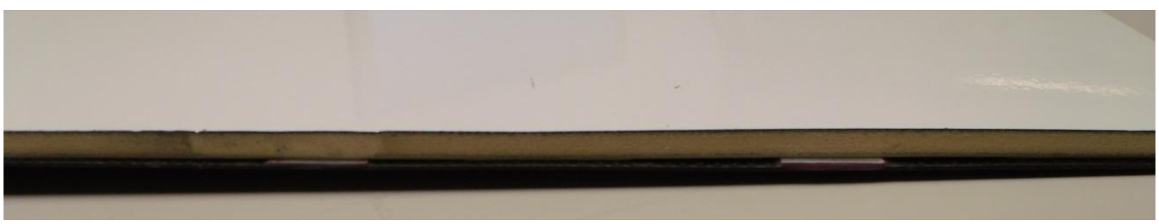


Figure 245: Panel FAS-5 edge view.

Figure 246: Panel FAS-5 shaded front view.

Figure 247: Panel FAS-5 tear (close-up view).

Figure 248: Panel FAS-6 front view.

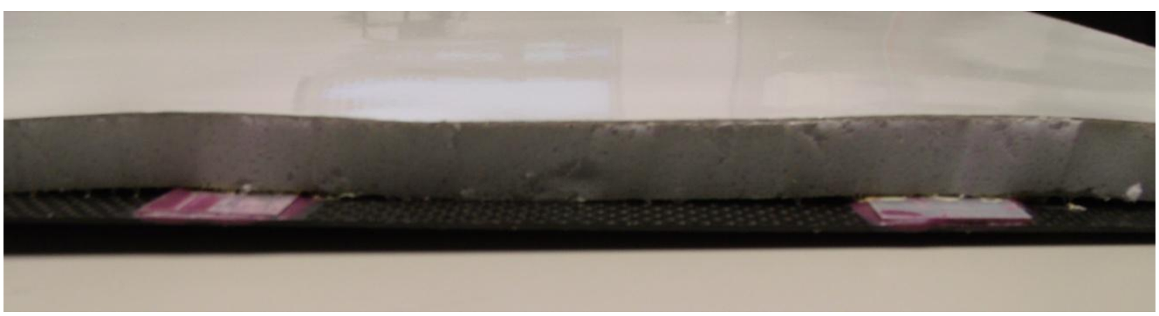


Figure 249: Panel FAS-6 edge view.

Figure 250: Panel FAS-6 shaded front view.

The visual indications that were recorded consisted of whether or not the various fasteners were visible at the outer layer and whether the 0.020” and 0.040” aluminum doublers were visible at the surface. The summary from the visual examinations are presented in Table 95. As can be seen in the table, none of the combinations investigated completely covered the surface geometry deviations, without some translation to the surface. All of the panels did well hiding the flush fasteners. The panels with Soric and metallic honeycomb cores did not hide the protruding head fasteners. The polyurethane core had mixed results, with the Innegra impact spreading layer showing a slight translation of the fasteners to the surface, but the carbon impact spreading layer hiding them. The Polydamp core panel did not translate any of the fastener displacements to the surface.

In order to further characterize these panels, physical measurements were taken for the following parameters: (1) panel deformation; (2) panel thickness over the 0.020” thick doubler; and (3) panel thickness over the 0.040” thick doubler. The overall panel deformation was measured by placing the panels on a flat table with the outer layer face down. The maximum height of the backside of the panel was measured along the bottom edge of the panel, and its height and location from the left edge were recorded. For characterization and data analysis, the nominal panel thickness was subtracted from the recorded value, to arrive at a computed value for the distance between the table and the outer layer of the panel. This value was compared across the various panel combinations and is shown in Figure 251.

Table 95 - Visual Examination Results for Aesthetic and Smoothing Panels

Panel ID:	FAS-1	FAS-2	FAS-3	FAS-4	FAS-5	FAS-6
Core Material:	3 mm Soric LRC	3 mm Soric LRC	¼” 3 pcf metallic honeycomb	1/4" 10 pcf PU	1/4" 10 pcf PU	Polydamp (1/2")
Impact Spreading Layer:	Innegra	Carbon ALS	Innegra	Innegra	Carbon ALS	Innegra
Lightning Strike Layer	LDS 50-01	None	LDS 50-01	LDS 50-01	None	LDS 50-01
Aesthetic Layer:	Integument Film	Integument Film	Integument Film	Integument Film	Integument Film	Integument Film
-4 Protruding	Visible	Visible	Visible	Slightly Visible	Not Visible	Not Visible
-6 Protruding	Visible	Visible	Visible	Slightly Visible	Not Visible	Not Visible
-5 Flush	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible	Not Visible
0.020" Al Doubler	Not Visible	Visible	Visible	Slightly Visible	Not Visible	Visible
0.040" Al Doubler	Not Visible	Visible	Visible	Slightly Visible	Slightly Visible	Visible

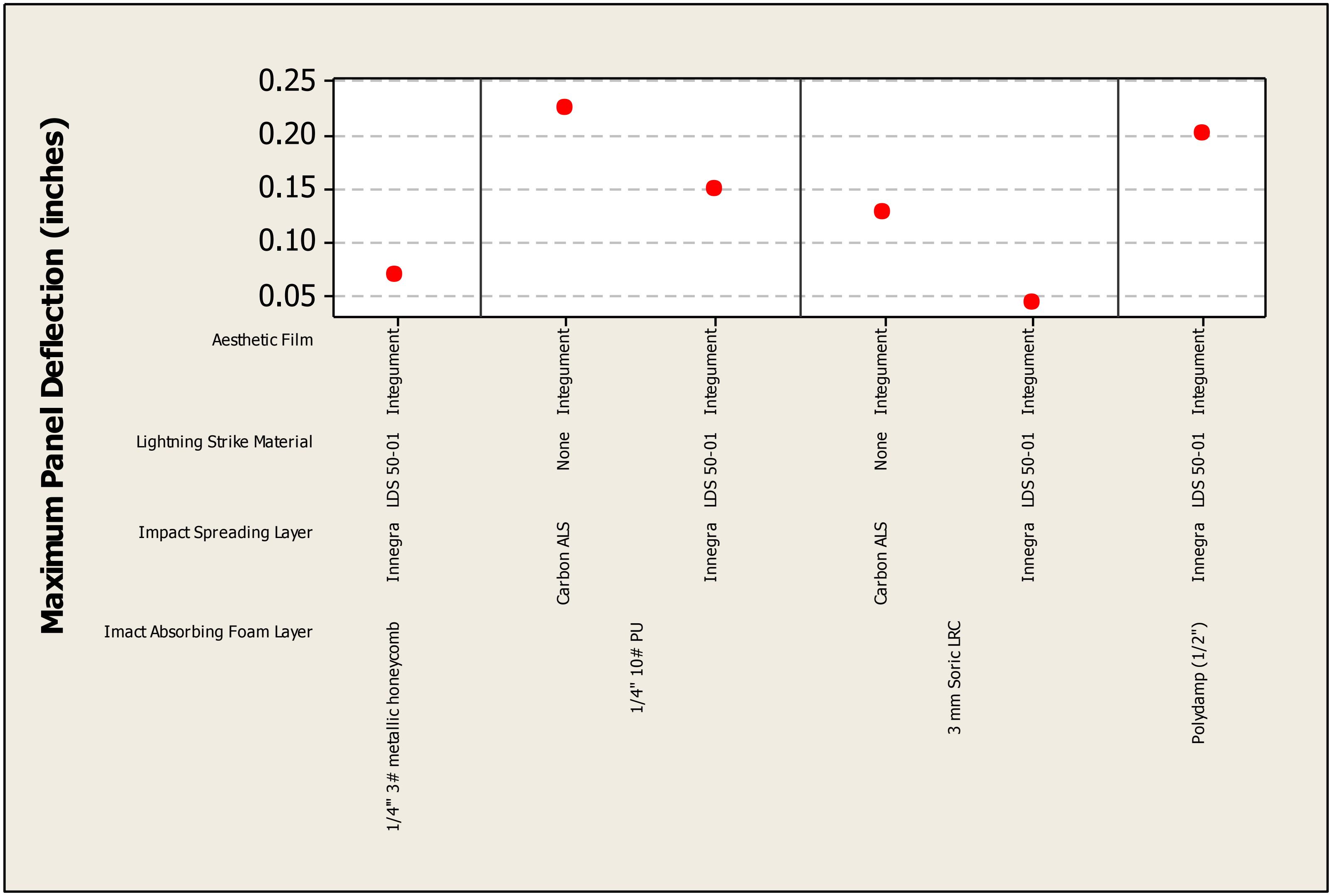


Figure 251: Computed maximum panel deformation.

The panel thicknesses over the two doublers were measured with a digital caliper. For reporting purposes, the nominal thickness of the panel was subtracted from the recorded value, as was the thickness of the particular item at each location. The resulting values were used in the comparisons of the different panel configurations as shown in Figure 252 and Figure 253.

There does not appear to be any strong correlation between panel deformation and impact absorbing layer as presented in Figure 251. There does appear to be a trend that shows that carbon fabric impact spreading layers may be creating larger deformations than the Innegra impact spreading layers for the core types where both spreading layers were used, but the sample size is likely too small to draw any definitive conclusions. It is surprising that the panel with the Polydamp impact absorbing layer has as much deformation as it does, as previous panels produced with this material showed much less deformation, but they were not coupled with the impact spreading layer.

Similarly, Figure 252 and Figure 253 show the results for the 0.020” and 0.040” aluminum doublers respectively. For the most part, the panels show small increases over the doublers, although it is noted that no allowance was made mathematically for the paste adhesive bonding thickness used to bond the doublers to the base panels. Unlike the previous round of tests, no negative thickness values associated were encountered with the Polydamp panels, suggesting that having the impact spreading layer in the stack-up has made the thickness measurement more robust.

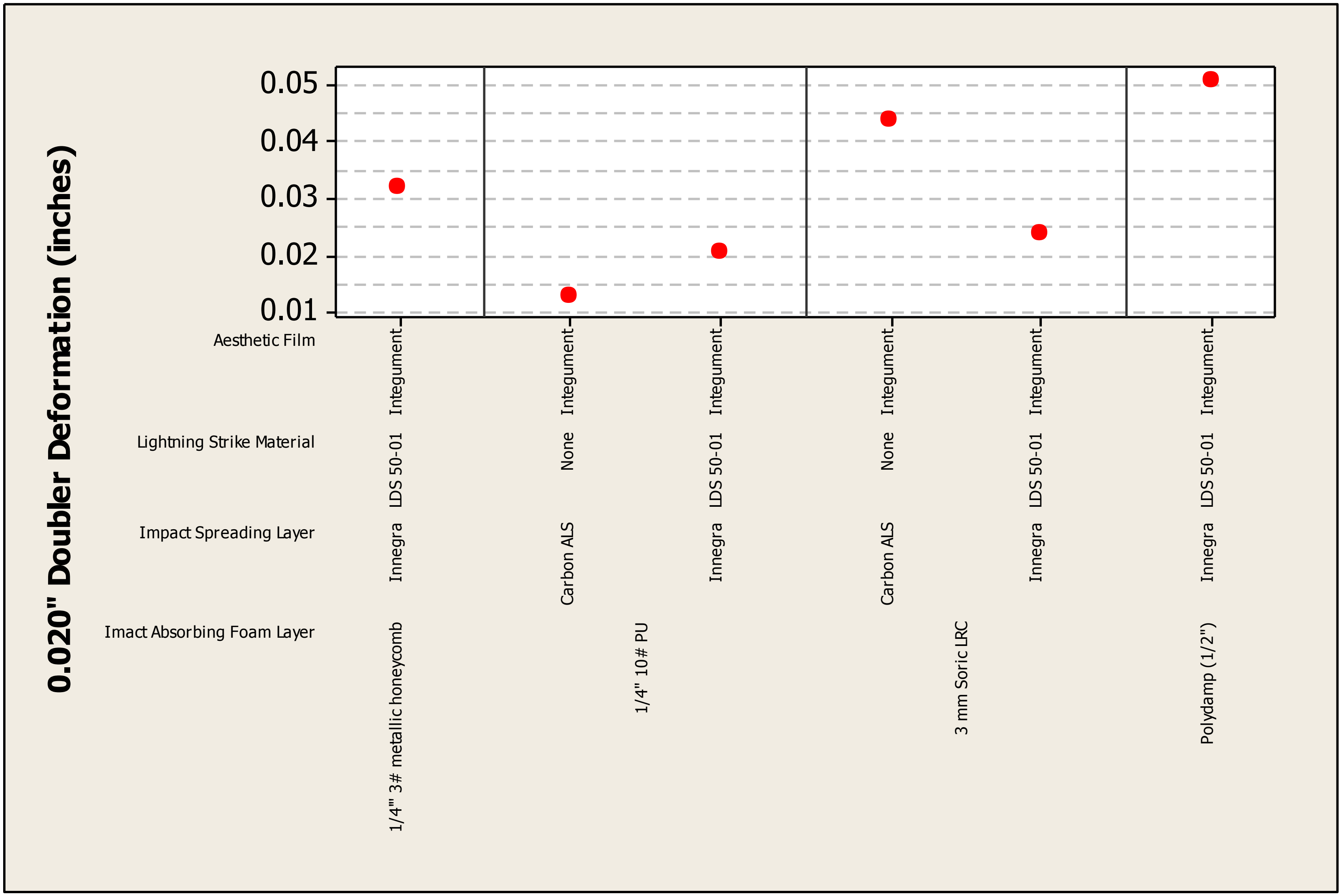


Figure 252: Computed deformation over 0.020" doubler.

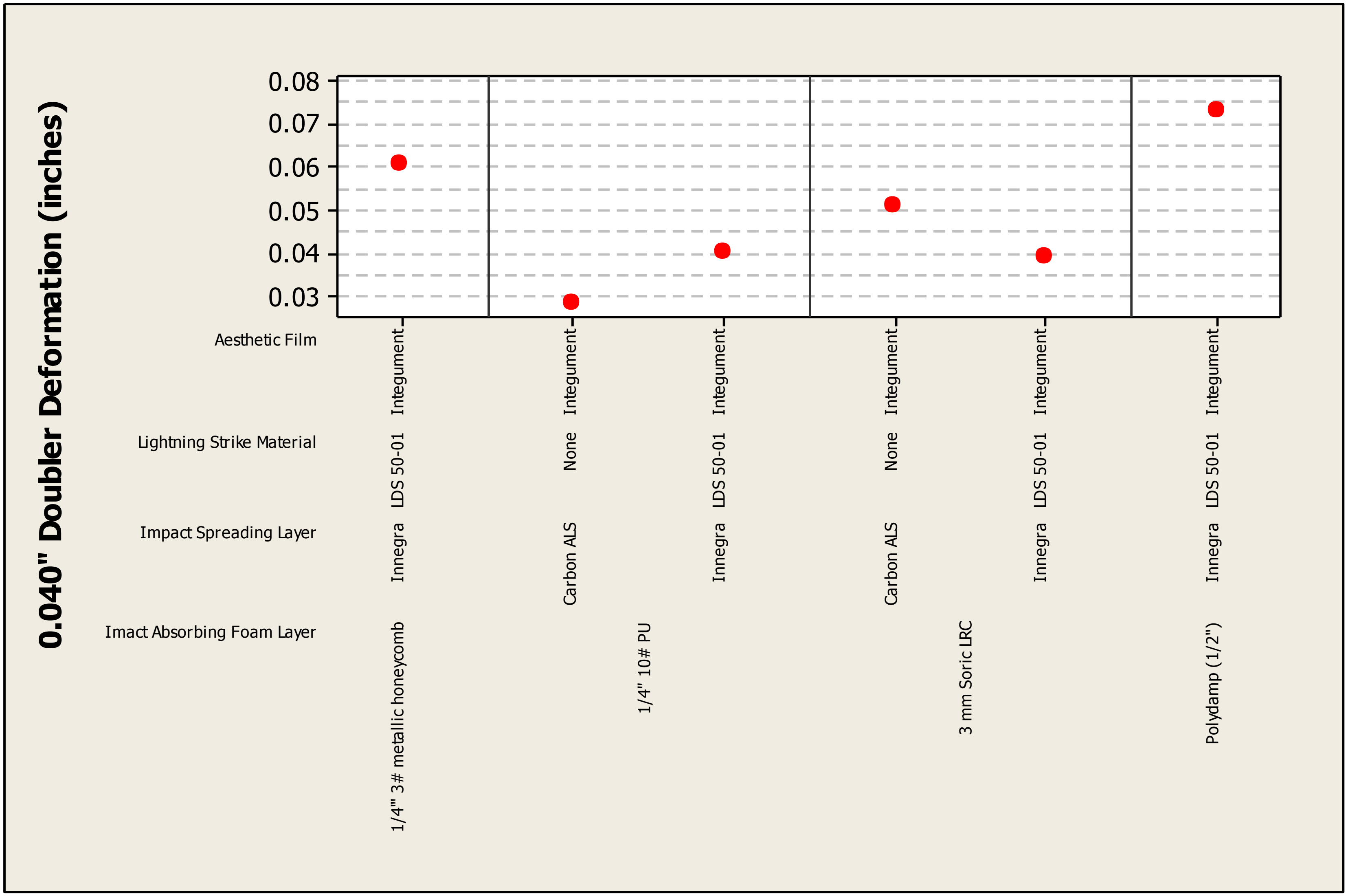


Figure 253: Computed deformation over 0.040" doubler.

8.4.2.2 ***Acoustic Panels***

The challenge with producing the acoustic panels was getting the Integument film applied in an aesthetically pleasing manner. The panels were 48” x 48”. The Integument film was in a roll 24” wide by 110’ long. Some kind of seam in the film was necessary. Two types of seams were tried (butt splice and overlapping).As will be seen in the pictures that follow, producing a seam that looks good was difficult.

The other problem was covering the entire panel without wrinkles or bubbles. Some of the panels had a slight curvature from the manufacturing process. Also, the panels were large. As shown in the pictures, wrinkles were a common occurrence while bubbles very occasionally appeared.

Pictures were taken of the acoustic test panels in direct sunlight. Those pictures are shown in Figure 254 through Figure 271.

Figure 254: Panel FAC-1 front view.

Figure 255: Panel FAC-1 close-up view 1.

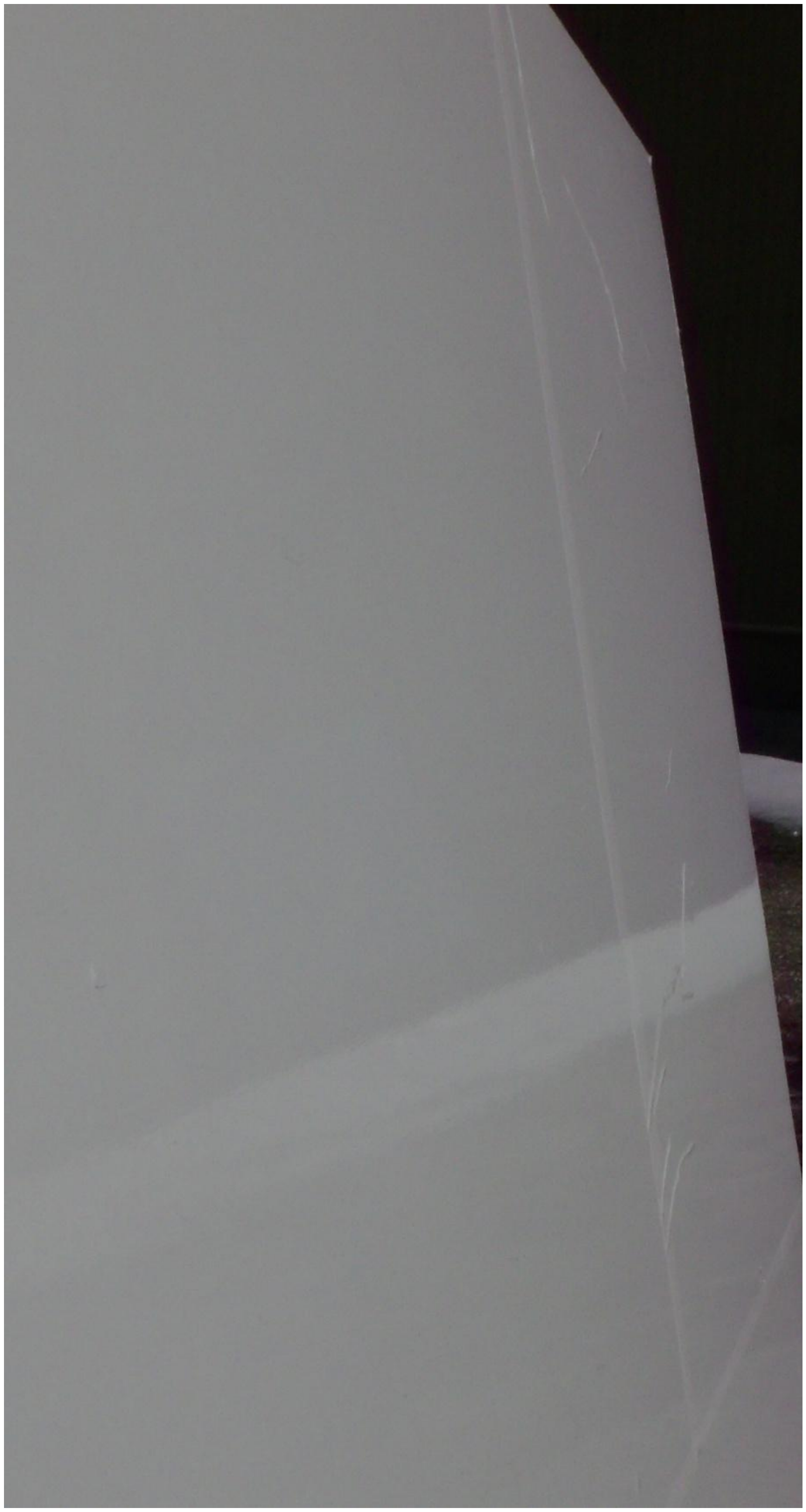


Figure 256: Panel FAC-1 close-up view 2.

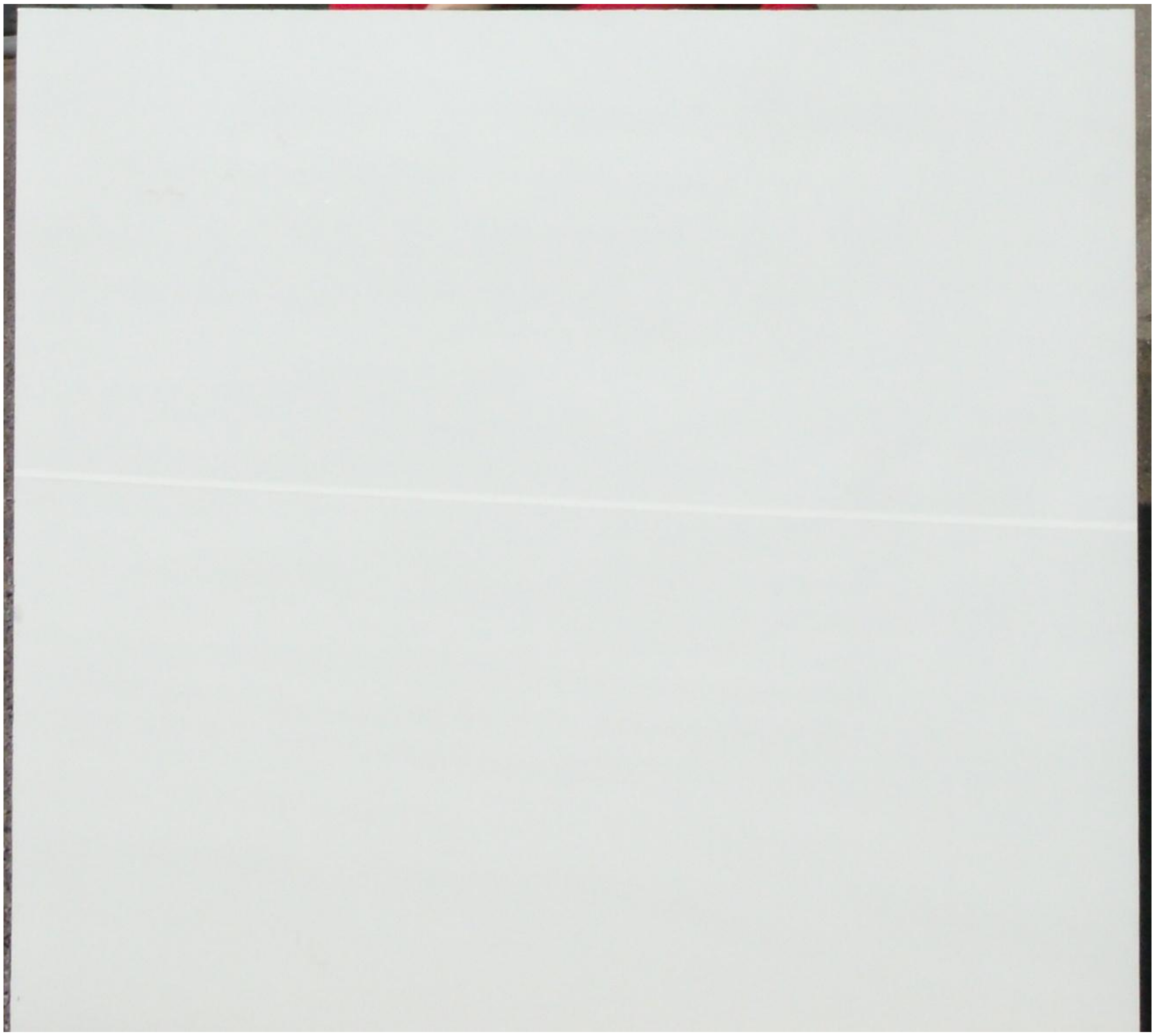


Figure 257: Panel FAC-2 front view.

Figure 258: Panel FAC-2 side view.

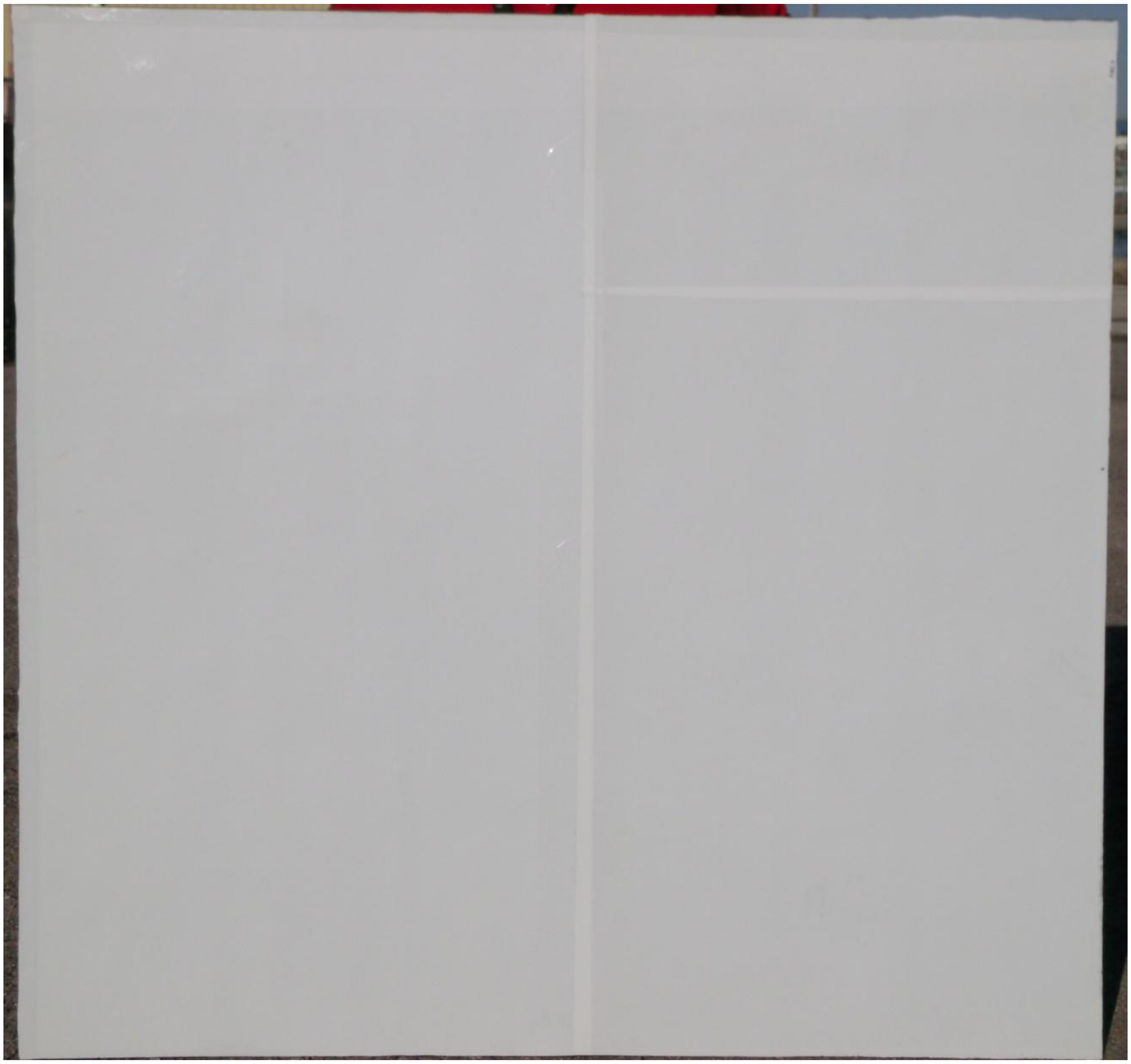


Figure 259: Panel FAC-3 front view.

Figure 260: Panel FAC-3 close-up view 1.

Figure 261: Panel FAC-3 close-up view 2.

Figure 262: Panel FAC-4 front view.

Figure 263: Panel FAC-4 close-up view 1.

Figure 264: Panel FAC-4 close-up view 2.

Figure 265: Panel FAC-5 front view.

Figure 266: Panel FAC-5 close-up view 1.

Figure 267: Panel FAC-5 close-up view 2.

Figure 268: Panel FAC-5 close-up view 3.

Figure 269: Panel FAC-6 angled view.

Figure 270: Panel FAC-6 close-up view 1.

Figure 271: Panel FAC-6 close-up view 2.

The panels fabricated for the acoustic testing were visually examined for outer layer surface anomalies prior to being shipped to the acoustic test lab. The results of these examinations are captured in Table 96.

All of the panels exhibited relatively smooth external surfaces, with the exceptions of a few areas of wrinkles that were introduced during the manufacturing process. Bubbles were not as large of an issue as they were in previous tests, as the aesthetic layer for all of these panels was supplied with PSA already applied from the supplier, which vastly minimized the potential of introducing bubbles in the stack-ups. Several of the panels did exhibit localized areas of wrinkles that were introduced during the application process. Working with these materials is very much an art, and several panels were able to be made without wrinkles, as shown in Table 96 and documented in the photos just presented. One of the panels, FAC-6, was produced with a butt splice in the aesthetic film layer, while all of the other panels were produced with overlap splices. Visually, the butt splice appears as a dark line at the intersection, whereas the overlap splices tend to stand out as a more opaque white stripe along the panel. Not all of the overlap splices were due to available film material sizes, as some were created when a significant amount of wrinkles were produced in the application, and local areas of the film were removed and new pieces spliced in to complete the application.

Table 96 - Visual Examination Results for Acoustic Panels

Panel ID	Core Material	Impact Spreading Layer	Lightning Strike Layer	Aesthetic Layer	Smoothness	Bubbles	Wrinkles	Splices	Other Issues
FAC-1	3 mm Soric LRC	Innegra	LDS 50-01	Integument Film	Overall Good	None	Yes	Overlap	None
FAC-2	3 mm Soric LRC	Carbon ALS	None	Integument Film	Overall Good	None	None	Overlap	None
FAC-3	1/4” 3 pcf metallic honeycomb	Innegra	LDS 50-01	Integument Film	Overall Good	None	Yes	Overlap	None
FAC-4	1/4" 10 pcf PU	Innegra	LDS 50-01	Integument Film	Overall Good	None	None	Overlap	Crease in core
FAC-5	1/4" 10 pcf PU	Carbon ALS	None	Integument Film	Overall Good	None	Yes	Overlap	Tear in surface
FAC-6	Polydamp (1/2")	Innegra	LDS 50-01	Integument Film	Overall Good	Yes, 1 Bubble	None	Butt	LDS 50-01 cut short

From a purely visual perspective, the acoustic panels would not be satisfactory quality for a typical business jet application, but might have been acceptable for a commercial transport application. The visual aspects of how butt and overlap splices are clearly visible would require some additional consideration, but might be able to be overcome by producing a film that is more opaque to start with.

8.5 Thermal Testing Results

Thermal analysis testing was performed on the aesthetic and smoothing panels in order to characterize how the material stack-ups would perform as thermal insulation. In order to support this testing, the test fixture fabricated for first-generation testing was mounted in the door opening of a Blue M convection laboratory oven. The test fixture was mounted into the opening through the use of several rare earth magnets and was sealed against the internal frames of the oven to prevent air leaks. An opening allowed for the panels to be mounted into the fixture through the use of a ring doubler and toggle clamps. A surface thermocouple was placed on the back surface of the mounted test panel, and the temperature rise over time was recorded. Additional thermocouples were mounted to aluminum plates and placed adjacent to the oven and in the oven, so that ambient and oven air temperatures could be recorded respectively. The test setup is shown in Figure 272through Figure 274.

Figure 272: Thermal performance test setup – mounting frame.

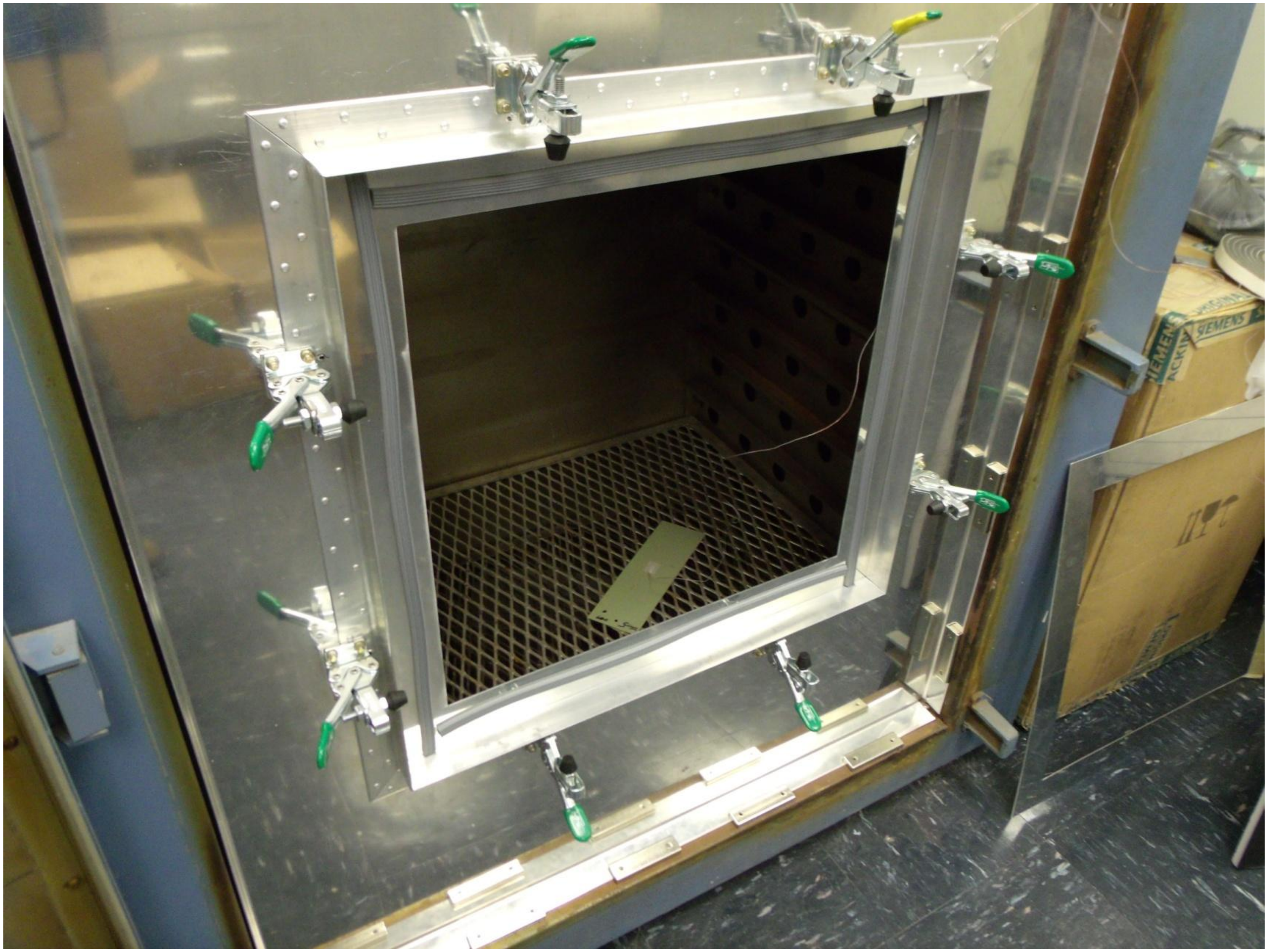


Figure 273: Thermal performance test setup – oven temperature.

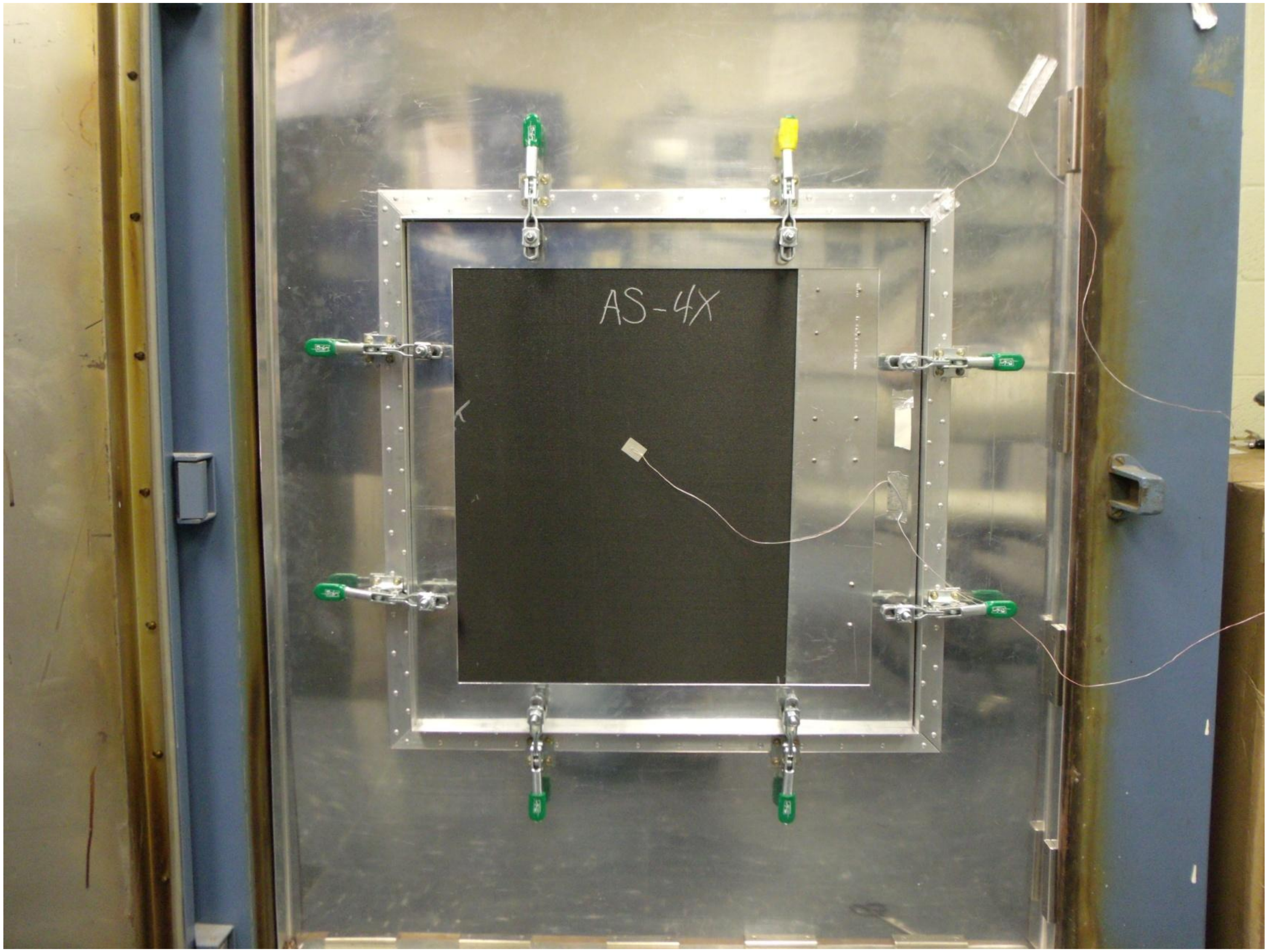


Figure 274: Thermal performance test setup – test in progress.

Prior to running a test, the oven was pre-heated to 160°F with a cover plate over the fixture opening. Once stabilized, a test panel was loaded into the fixture, and the digital data recorder for the thermocouples was started. Once the back-side temperatures of the panels stabilized, the recording was stopped and the process was repeated with the next panel. Throughout all of the thermal testing of the panels, the oven temperature remained within ±5° of the 160°F set point, and the ambient room temperature was fairly consistent.

Figure 275 shows the graphical plot of the data generated from the aesthetic and smoothing series of panels. As expected, the primary driver of thermal insulation performance is the impact absorbing layer material. Comparison of FAS-1 to FAS-2 and FAS-4 to FAS-5 show a minor secondary effect of the impact spreading layer when placed on the same kind of impact absorbing layer, but it is not consistent between the two sets of panels. Furthermore, the Soric core-based panels show more disparity between themselves as compared to the Polyurethane base cores. This is possibly due to a difference in the amount of resin infused into the FAS-1 versus FAS-2 panel and process variation that might be encountered with the Soric material versus the Polyurethane core material.

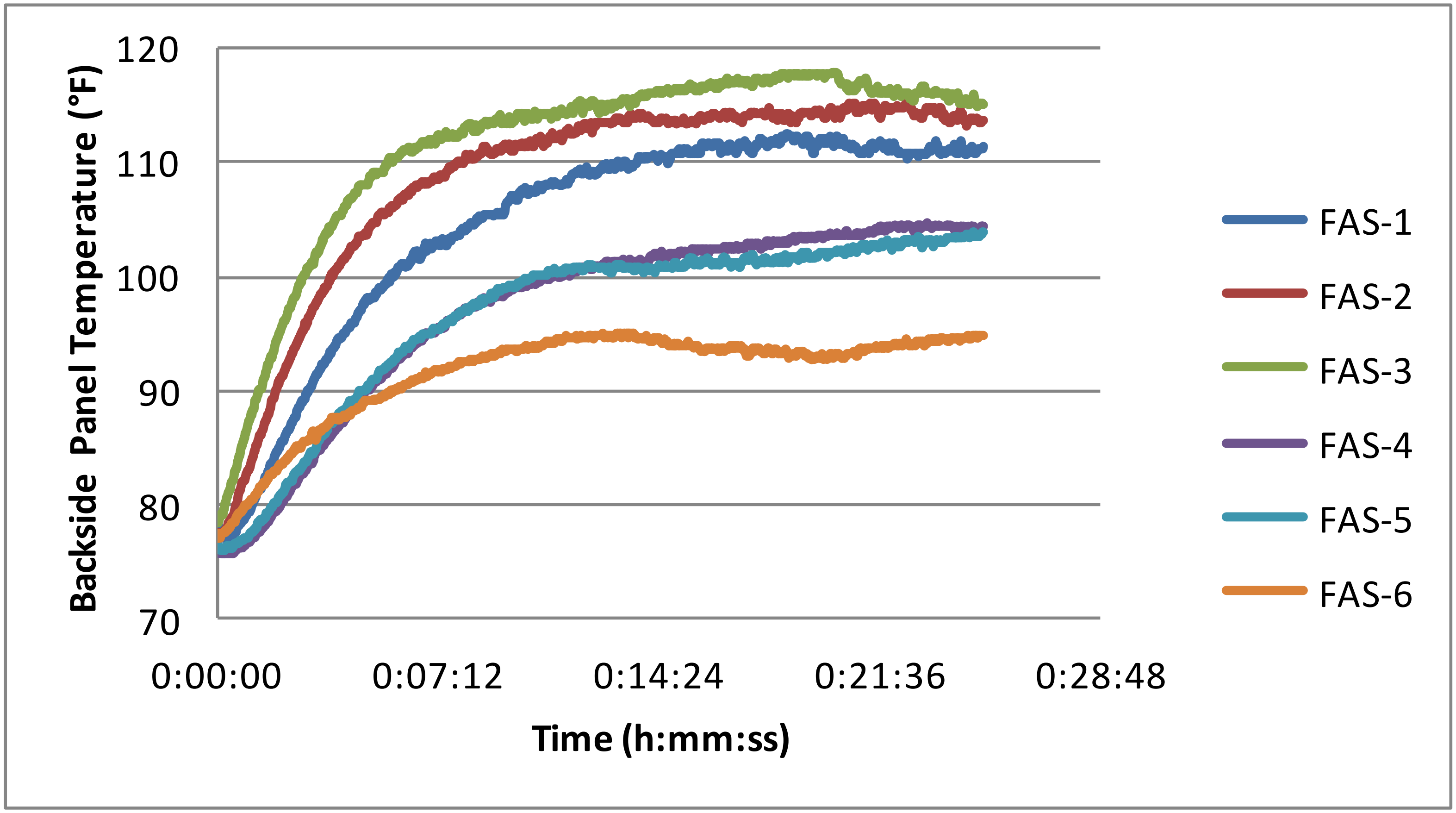


Figure 275: Thermal performance of panels.

Table 97 summarizes maximum temperatures obtained from each of the panels shown in Figure 275. In previous tests, an unmodified base substrate showed a maximum temperature of 125.4°F. The best performing core was the ½" Polydamp melamine foam with a maximum temperature of 95.0°F, and the worst performing core was the ¼" thick metallic honeycomb based panel which had a temperature of 118°F. The Soric was second worst, and the Polyurethane core was second best at providing thermal insulation.

Table 97 - Summary of Thermal Performance Trends from Aesthetic and Smoothing Panels

Panel ID	Core Type	Max. Temp. (°F)
FAS-1	3mm Soric LRC	112.5
FAS-2	3mm Soric LRC	115.2
FAS-3	¼" 3 pcf Aluminum Honeycomb	118.0
FAS-4	10 pcf Polyurethane	104.7
FAS-5	10 pcf Polyurethane	104.0
FAS-6	½" Polydamp	95.0

8.6 Acoustics

The six STAR-C^2 skin definitions were built into 48" x 48" test panels. The protective skin panels were compared to two bare base substrate composite panels and one conventional aluminum configuration. Transmission loss of each panel was measured per ASTM E90 and compared. The goal was to see if any of the six protective skin concepts were as effective at noise reduction as conventional aluminum construction. If so, the STAR-C^2 protective skin would not require any interior insulation, resulting in a weight savings compared to conventional configurations of today.

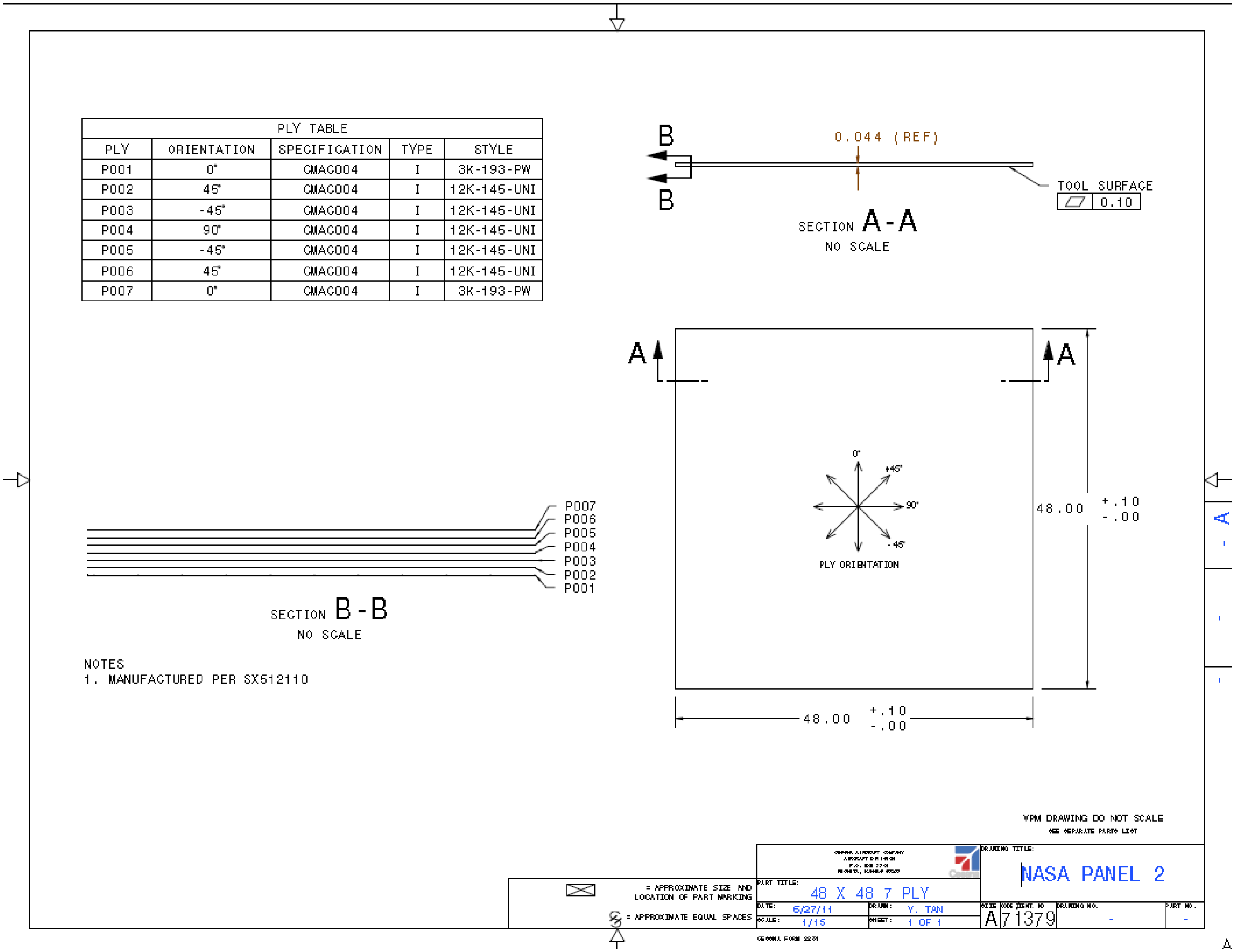
A second set of tests were conducted with a variation of conventional noise reduction materials using one of the protective skins and the aluminum panel. This provided data on how effective each of the currently used interior insulating elements for aluminum fuselages is at contributing to transmission loss on both a STAR-C^2 skin and an aluminum skin.

8.6.1 Test Panel Definition

The STAR-C^2 test panels consisted of two parts: the base substrate panels and the protective skins. The aluminum test panel simulated a current technology aluminum aircraft fuselage with conventional internal noise protection. All panels were manufactured to 48" x 48" and then cut down to 45" x 47" to allow the fiberglass insulation bags to fit exactly.

8.6.1.1 ***Base Substrate Panel Definition and Actual Construction***

The base substrate panels were seven layers of carbon fiber material with the inner five layers uni-directional material at differing orientations and the outer layer a plain weave material as shown in Figure 276. The only planned difference between these panels and the panels for the other testing was size – these were 48" x 48" instead of 24" x 24".



PLY	ORIENTATION	SPECIFICATION	TYPE	STYLE
P001	0°	CMAC004	I	3K-193-PW
P002	45°	CMAC004	I	12K-145-UNI
P003	-45°	CMAC004	I	12K-145-UNI
P004	90°	CMAC004	I	12K-145-UNI
P005	-45°	CMAC004	I	12K-145-UNI
P006	45°	CMAC004	I	12K-145-UNI
P007	0°	CMAC004	I	3K-193-PW

Figure 276: Base substrate panel drawing.

Unfortunately there was confusion with a specification and the manufacturing of the base substrate panels. The manufacturing specification on the drawing (SX512110) calls out an overlap between 0.5" to 2.0" of the material whenever it is necessary to place pieces of the material next to each other. That was the correct specification for the materials used to build the base substrate panels for the first round of testing (although the material was laid out so that overlaps were not necessary for that round of testing). The correct specification (CSAC005) says that butt splicing should be used whenever pieces of the material must be placed next to each other. Some panels were made with material overlaps of at least 0.5" while others were made without those overlaps.

A picture of the bag side of one of the acoustic panels with overlap was shown in Figure 116. The overlaps are clearly visible. The overlaps are also visible in the thermographic image which was shown in Figure 117.

The goal was to have all of the acoustic panels made with overlaps so they would be consistent. However, an attempt to get impact panels made without overlaps resulted in acoustic panels also being made without overlaps ("no ol" as shown in Table 98). There is a difference of about 0.12 lbs (out of 5.94 lbs). This is a 2% difference which was not expected to cause a difference in acoustic response. However, because the attachment of protective skins to panels with overlap and panels without overlap is somewhat random, there was no way to infer a difference based on differences between panels with protective skins. Therefore, one bare base substrate panel with overlaps and one without overlaps were tested for direct comparison. Testing showed there was no difference. If there had been a difference, a delta could have been determined to adjust the other panels for consistency.

Table 98 - Acoustics Base Substrate Panel Weights

Test Article Number	Base Substrate Panel Number	Bare Substrate Panel Weight, lbs	Bare Substrate Panel Areal Density, psf
FAC-1	18190	5.94	0.371
FAC-2	18129 (no ol)	5.82	0.364
FAC-3	19953 (no ol)	5.8	0.363
FAC-4	18193	5.95	0.372
FAC-5	18195	5.94	0.371
FAC-6	18194 (no ol)	5.82	0.364
FAC-7	18192 (no ol)	5.8	0.363
FAC-8	18191	5.94	0.371

The conventional aluminum fuselage simulation (Panel FAC-9) was a 0.040" sheet of aluminum. The areal density of the aluminum is 0.547 psf.

The fuselage frames and stringers were simulated using wooden pieces glued onto the back of the base substrate panel and aluminum panel. Surface preparation of the carbon fiber base substrate panel was necessary. The drawing of the frames and stringers arrangement is shown in Figure 277. A picture of a

panel with frames and stringers laid out is shown in Figure 278. A close-up view of the wooden frame is shown in Figure 279. The frame is a "C" section to minimize weight, provide some stiffness similar to a composite frame, and provide a continuous surface on which to mount the isolators. A close-up view of the wooden stringer is shown in Figure 280. Wood was also removed from the center of the stringer to minimize weight. The weight concern was driven by minimizing the amount of acoustic energy absorbed by the wood.

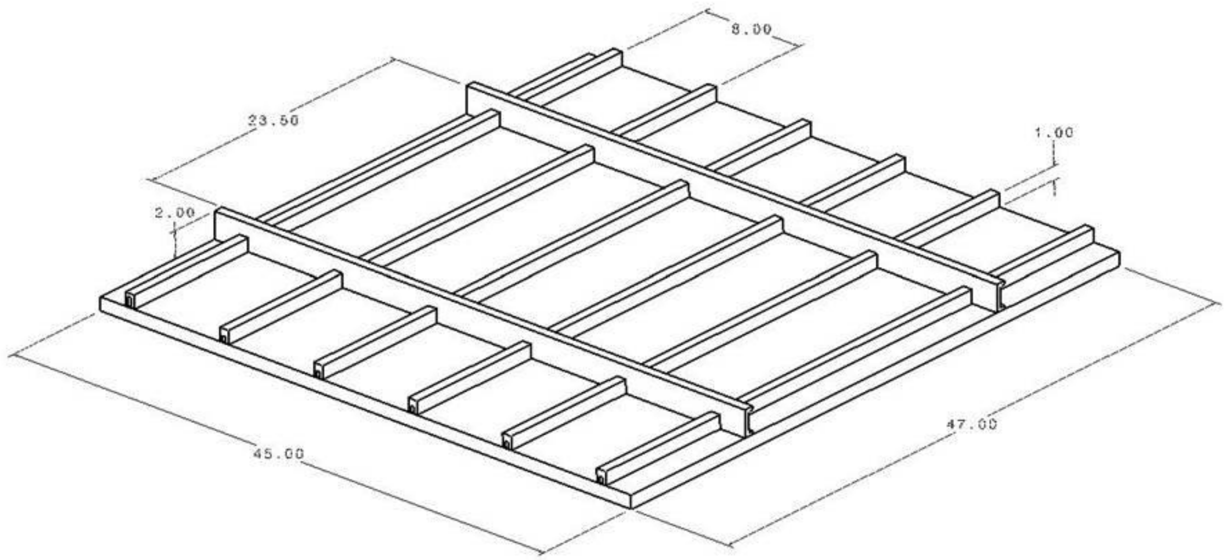


Figure 277: Frame/stringer/fuselage representation drawing.

Figure 278: Frame/stringer arrangement.

Figure 279: Close-up view of frame.

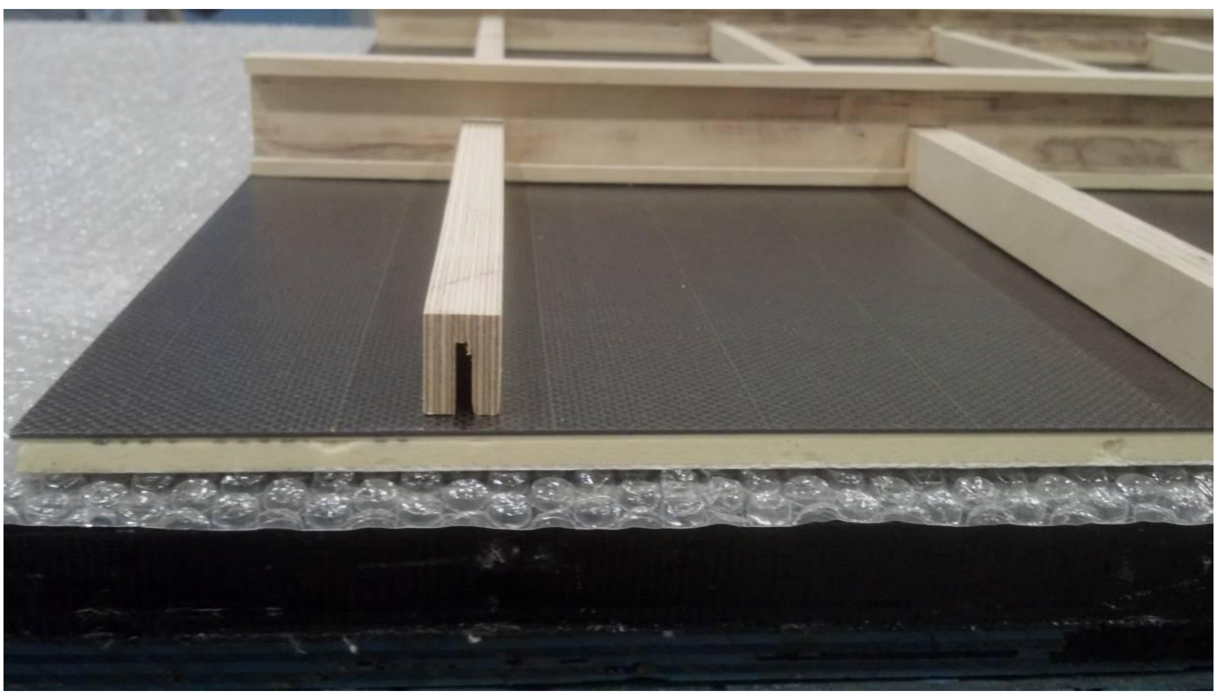


Figure 280: Close-up view of stringer.

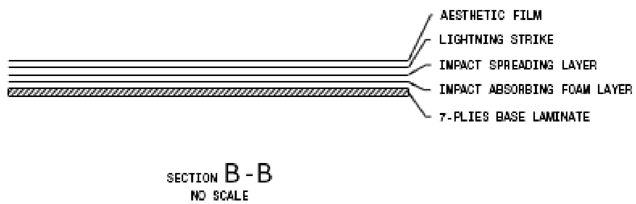
8.6.1.2 ***Protective Skin Definition***

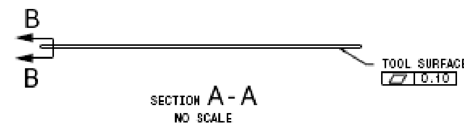
The six protective skin definitions for the STAR-C^2 panels are shown in Table 99. Two of the panels used Soric, two used 0.25” 10-lb polyurethane foam, one used 0.25” 3-lb metallic honeycomb, and one

used 0.25" Polydamp Hydrophobic Melamine for the impact absorbing layer. The impact spreading/lightning protection layer(s) were either Innegra with LDS 50-01 or Carbon ALS. All panels had Integument film as the outer covering. All except the Polydamp were bonded to the base substrate panel using 3M 4950 double-sided tape; the Polydamp had a pressure-sensitive adhesive on both sides to attach to the base substrate panel and the Innegra. A drawing of the protective skins is shown in Figure 281.

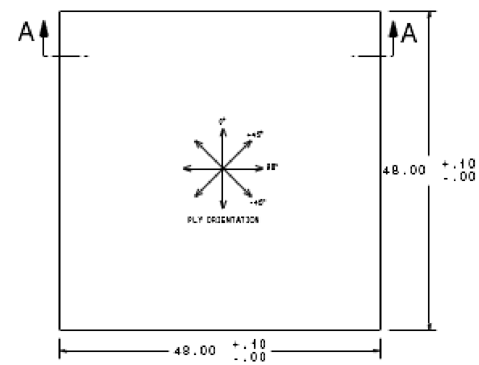
Table 99 - Protective Skin Definitions

Panel #	Interface	Impact Absorbing Layer	Interface	Impact Spreading Layer	Interface	Lightning Strike	Aesthetic Film
FAC-1	3M 4950	3 mm Soric LRC	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-2	3M 4950	3 mm Soric LRC	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FAC-3	3M 4950	1/4' 3# metallic honeycomb	Grade 30 Adhesive	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-4	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-5	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FAC-6	None	Polydamp (1/2")	None	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA





PANEL ID	INTERFACE	IMPACT ABSORBING LAYER	INTERFACE	IMPACT SPREADING LAYER	INTERFACE	LIGHTNING STRIKE	AESTHETIC FILM
FAC-0	None	None	None	None	None	None	None
FAC-1	3M 4950	3 mm Soric LRC	CSAC006 TYPE 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-2	3M 4950	3 mm Soric LRC	CSAC006 Type 1 Resin	Carbon ALS	None	None	Integument Film with PSA
FAC-3	3M 4950	1/4" 3# Metallic Honeycomb	Grade 30 Adhesive	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-4	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA
FAC-5	3M 4950	1/4" 10# PU	CSAC006 Type 1 Resin	Carbon ALS	NONE	None	Integument Film with PSA
FAC-6	None	Polydamp (1/2")	None	Innegra	CSAC006 Type 1 Resin	LDS 50-01	Integument Film with PSA



48 X 48 7 PLY
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Figure 281: Protective skins definition drawing.

The noise protection scheme for the conventional aluminum fuselage is shown in Figure 282. There were no materials on the outside of the aluminum. The frame and stringer simulation was bonded to the inside of the aluminum. Between the frames next to the aluminum was ADC-324 damping material. Between-frame treatment (on top of the ADC-324) was 2" of 0.6 psf bagged fiberglass. Over-frame treatment (on top of the fiberglass) was a 0.25" layer of Nomex with holes to accommodate the isolators.

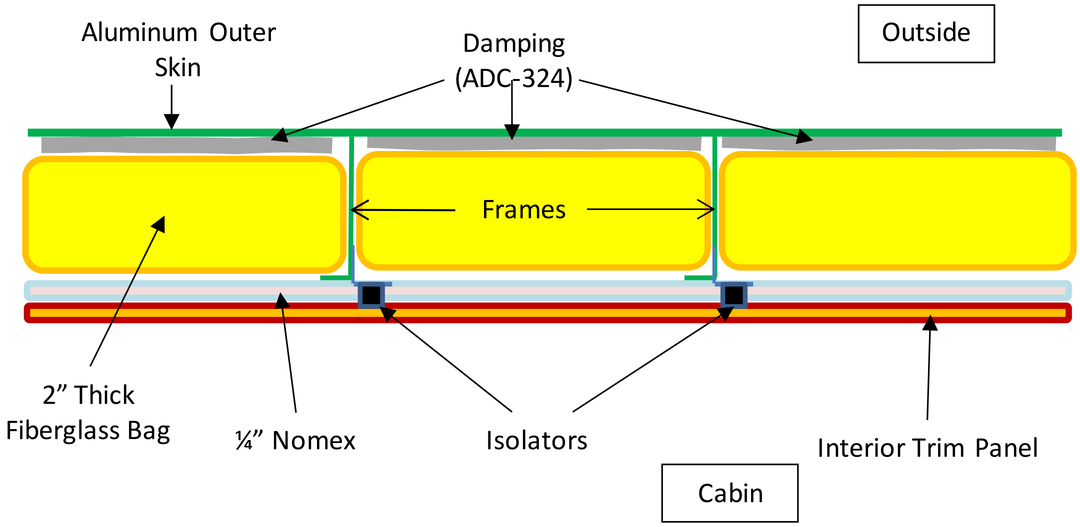

Figure 282: Schematic of conventional aluminum baseline panel.

The test article was closed out with an interior acoustic trim panel which is identical to the panel currently used on Cessna Citation jets to close out the space between the side of fuselage and the interior of the aircraft. The panel manufactured for this effort was made 48" x 48" and cut down to 45" x 47". A side view of the layers of the panel is shown in Figure 283. The layers shown in the figure are defined in Table 100. The notes in Table 100 are shown in Table 101. The trim panel was attached with 4 isolators (LORD part number J-7444-14) by quarter turn fasteners.

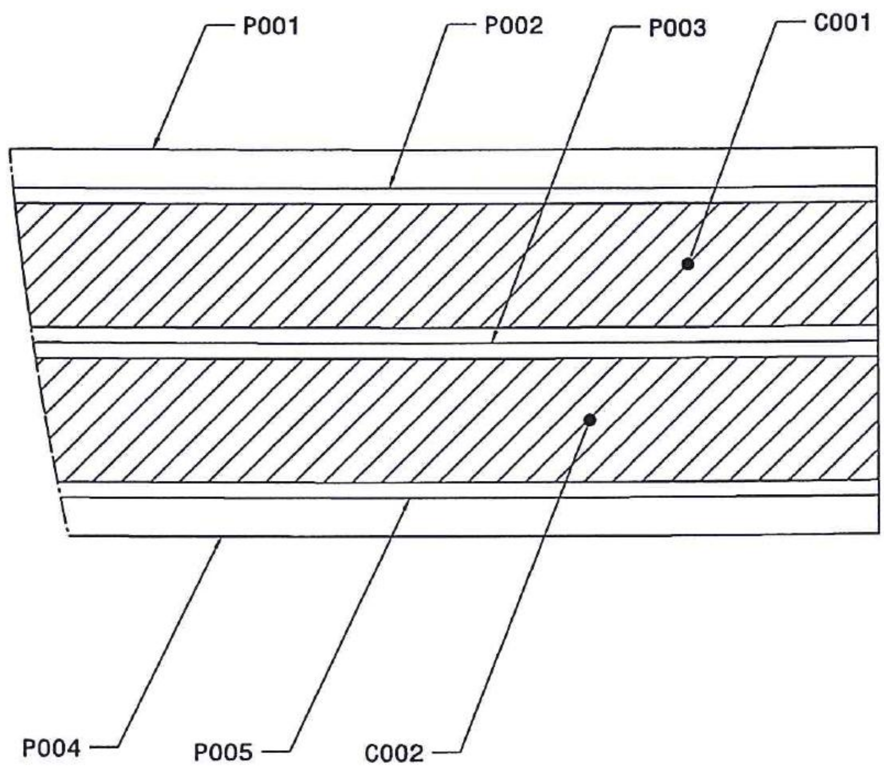

Figure 283: Interior trim panel ply arrangement.

Table 100 - Interior Trim Panel Ply Table

MATERIAL TABLE			
PLY	MATL	NOTE	ORIENT
P001	WGF	1	OPT
P002	WGF	2	OPT
P003	DMP	4	OPT
P004	WGF	1	OPT
P005	WGF	2	OPT
C001	FC	3	OPT
C002	FC	3	OPT

Table 101 - Notes Definitions

Notes:

<1> (WGF) WOVEN PHENOLIC FIBERGLASS PREPREG 120 GLASS PER CMNP087, TYPE I, CLASS B, GRADE M, STYLE 120. MANUFACTURER: F441624.

<2> (WGF) WOVEN PHENOLIC FIBERGLASS PREPREG 7781 GLASS PER CMNP087 TYPE I, CLASS B. GRADE M, STYLE 7781. MANUFACTURER: F441621.

<3> (FC) FOAM CORE PER CMNP060, TYPE I, GRADE A. MANUFACTURER: P440611 (0.125 PERFORATED).

<4> (DMP) SJ2016 SCOTCHDAMP, TYPE 1210. MANUFACTURER: P439006.

The definitions of test panel configurations for comparison of STAR-C^2 protective skins to conventional construction are shown in Table 102. FAC-1 through FAC-6a are the STAR-C^2 protective skins. They only had the interior trim panel as shown in Figure 284. The two panels to compare the effects of overlap versus no overlap were FAC-7 and FAC-8. Their test configuration is shown in Figure 285. They also had the interior trim panel. Results from FAC-7 and FAC-8 were compared to see if the overlap and additional base substrate panel mass had any effect on noise reduction. FAC-1 through FAC-6a were compared to FAC-9e, the conventional aluminum noise insulation panel.

In addition to comparing the protective skin panels to a traditional aluminum fuselage arrangement, data was collected on how the various noise insulation materials (besides the STAR-C^2 protective skins) affect the transmission loss. One protective skin was used for comparison. FAC-6 was the preferred candidate because the Polydamp Hydrophobic Melamine (impact absorbing layer) is a material currently used for interior noise insulation and because the Melamine was the favorite material from the first-generation skins. Speculation was that FAC-6 would provide the greatest noise reduction of any of the protective skins. The aluminum was also used to do an insulation material buildup.

Table 102 - Test Matrix to Compare STAR-C2 Panels to Conventional Construction

Panel #	Panel	Damping	Between Frame Treatment	Overframe Treatment	Interior Trim Panel
FAC-1	Composite - overlap	Protective Skin	None	None	Yes
FAC-2	Composite - no overlap	Protective Skin	None	None	Yes
FAC-3	Composite - no overlap	Protective Skin	None	None	Yes
FAC-4	Composite - overlap	Protective Skin	None	None	Yes
FAC-5	Composite - overlap	Protective Skin	None	None	Yes
FAC-6a	Composite - no overlap	Protective Skin	None	None	Yes
FAC-7	Composite - no overlap	Plain	None	None	Yes
FAC-8	Composite - overlap	Plain	None	None	Yes
FAC-9e	Aluminum	ADC-324	2" - 0.6 psf Fiberglass	1/4" Nomex	Yes

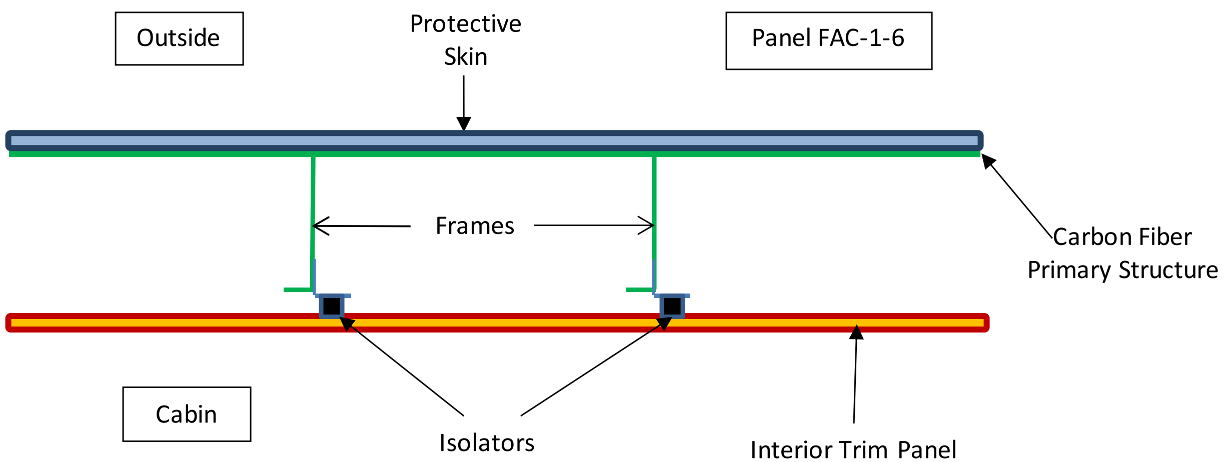

Figure 284: Protective skin test panel configuration.

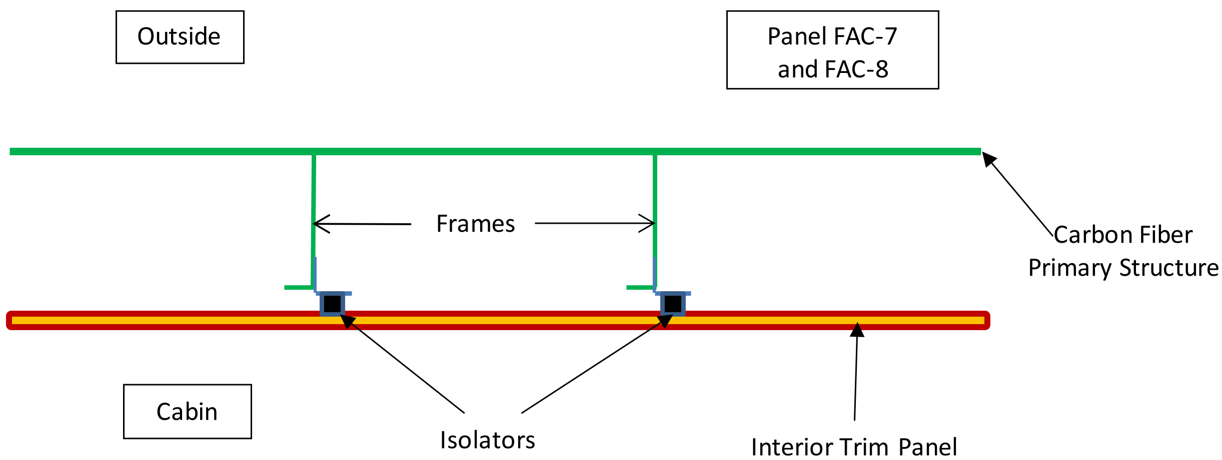

Figure 285: Overlap versus no overlap test panel configuration.

The definition of the panel configurations to conduct the transmission loss material build-ups is shown in Table 103. FAC-6a was the baseline STAR-C^2 panel; it was shown conceptually in Figure 284. FAC-6b added the 0.25" Nomex (shown in Figure 286). FAC-6c added the 2" 0.6 lbs/ft^2 Fiberglass bag as shown in Figure 287. Finally, FAC-6d left the Fiberglass bag while removing the Nomex (see Figure 288). Configurations FAC-9a through FAC-9f were the same idea using the aluminum skin rather than the base substrate panel and protective skins. Configuration 9e was the conventional aluminum noise protection construction. Configuration 9f was the same as the baseline conventional aluminum construction except the Nomex was replaced with a layer of 1" Fiberglass. FAC-9h replaced the 1" Fiberglass with a 1" Fiberglass with Septum (essentially a heavy vinyl inside the Fiberglass bag). In addition to the noise reduction provided by each of these configurations, weight of the overall configuration was also a critical test result.

Table 103 - Transmission Loss Material Build-Up Study Panel Definitions

Panel #	Panel	Damping	Between Frame Treatment	Overframe Treatment	Isolated Trim Panel
FAC-6a	Composite	Protective Skin	None	None	Yes
FAC-6b	Composite	Protective Skin	None	1/4" Nomex	Yes
FAC-6c	Composite	Protective Skin	2" - 0.6 lb/sqrft Fiberglass	1/4" Nomex	Yes
FAC-6d	Composite	Protective Skin	2" - 0.6 lb/sqrft Fiberglass	None	Yes
FAC-9a	Aluminum	None	None	None	None
FAC-9b	Aluminum	None	None	None	Yes
FAC-9c	Aluminum	ADC-324	None	None	Yes
FAC-9d	Aluminum	ADC-324	None	1/4" Nomex	Yes
FAC-9e	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1/4" Nomex	Yes
FAC-9f	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	None	Yes
FAC-9g	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1" Fiberglass	Yes
FAC-9h	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1" Fiberglass with Septum	Yes

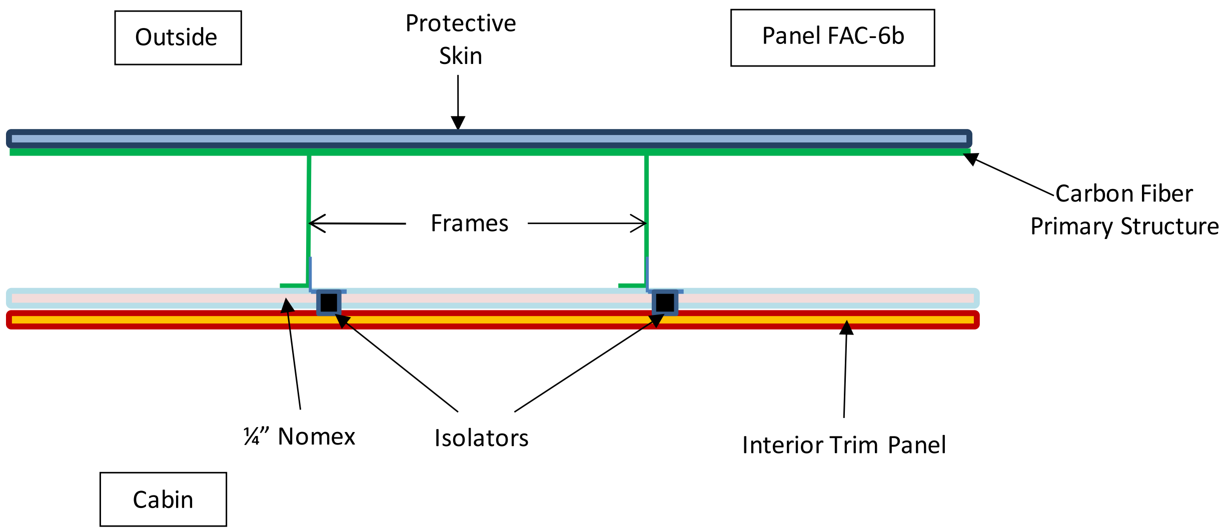

Figure 286: Panel FAC-6b layout (add over-frame Nomex).

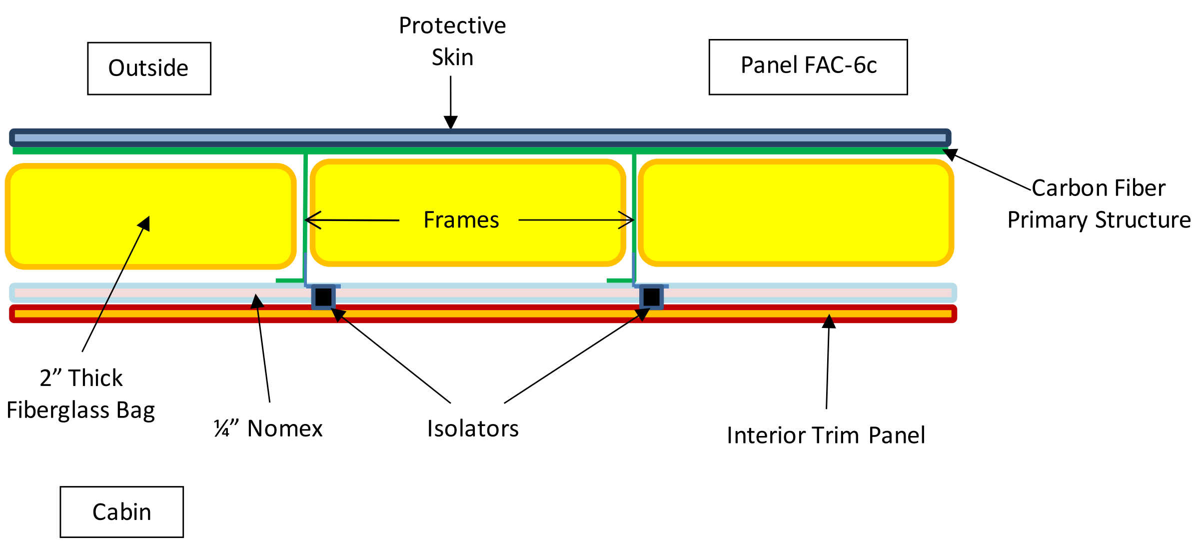

Figure 287: Panel FAC-6c layout (add between-frame fiberglass).

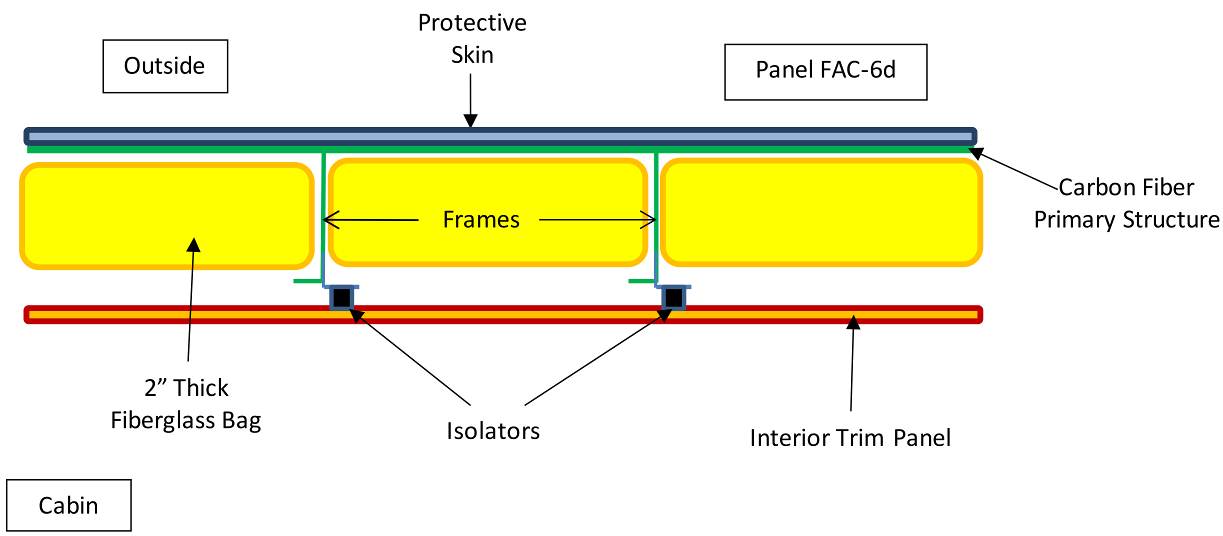

Figure 288: Panel FAC-6d Layout (Remove over-frame Nomex).

A total of 20 runs with various configurations of fuselage simulations and noise insulation materials was identified to cover all of the conditions in Table 102 and Table 103**.** In order to minimize test time, the runs were organized to minimize changes between runs. The testing run table is shown in Table 104. Run 13 description was changed to add the trim panel and not add damping to allow a comparison of damping performance on an aluminum panel with the trim panel.

Table 104 - Test Sequence

Run #	Panel #	Panel	Damping	Between Frame Treatment	Overframe Treatment	Isolated Trim Panel	Change
1	FAC-6a	Composite - no overlap	Protective Skin	None	None	Yes	
2	FAC-6b	Composite - no overlap	Protective Skin	None	1/4" Nomex	Yes	Add Nomex
3	FAC-6c	Composite - no overlap	Protective Skin	2" - 0.6 lb/sqrft Fiberglass	1/4" Nomex	Yes	Add 2" Fiberglass
4	FAC-6d	Composite - no overlap	Protective Skin	2" - 0.6 lb/sqrft Fiberglass	None	Yes	Remove Nomex
5	FAC-1	Composite - overlap	Protective Skin	None	None	Yes	Change Structural Panel
6	FAC-2	Composite - no overlap	Protective Skin	None	None	Yes	Change Structural Panel
7	FAC-3	Composite - no overlap	Protective Skin	None	None	Yes	Change Structural Panel
8	FAC-4	Composite - overlap	Protective Skin	None	None	Yes	Change Structural Panel
9	FAC-5	Composite - overlap	Protective Skin	None	None	Yes	Change Structural Panel
10	FAC-7	Composite - no overlap	Plain	None	None	Yes	Change Structural Panel
11	FAC-8	Composite - overlap	Plain	None	None	Yes	Change Structural Panel
12	FAC-9a	Aluminum	None	None	None	None	Change Structural Panel
13	FAC-9b	Aluminum	None	None	None	Yes	Add Trim Pannel
14	FAC-9c	Aluminum	ADC-324	None	None	Yes	Add Skin Damping
15	FAC-9d	Aluminum	ADC-324	None	1/4" Nomex	Yes	Add Nomex
16	FAC-9e	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1/4" Nomex	Yes	Add 2" Fiberglass
17	FAC-9f	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	None	Yes	Remove Nomex
18	FAC-9g	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1" Fiberglass	Yes	Move Panel Isolator Brackets and Add 1" Fiberglass
19	FAC-9h	Aluminum	ADC-324	2" - 0.6 lb/sqrft Fiberglass	1" Fiberglass with Septum	Yes	Replace 1" fiberglass with 1" Fiberglass with Septum
20	FAC-6a	Composite - no overlap	Protective Skin	None	None	Yes	Repeat of First Panel For Check on Variation

8.6.2 Testing

8.6.2.1 *Test Facility*

The ETS-Lindgren Acoustic Research Laboratory located in Cedar Park, Texas was used for this testing. Sound transmission loss measurement at ETS-Lindgren is measured in accordance with ASTM E90 “Standard Test Method for Laboratory Measurement of Airborne Sound Transmission Loss of Building Partitions and Elements” (ref. 20). The test facility is a NVLAP (National Voluntary Laboratory Accreditation Program)-accredited laboratory with Scope of Accreditation under Lab Code 100286-0.

8.6.2.2 *Test Setup*

The test specimens were mounted in a test window opening between two reverberation chambers. The test window was sized to fit the 47”x45” panels with 1/16” edge margin. A ¼” lip with 1/8” thick foam was provided on the source side of the test opening to provide a stop for consistent panel placement in the opening to 45-1/8” x 47-1/8”. All edges of the panel on the receiver side of the opening were sealed with duct putty. Pictures of the various panels installed from both the source room and the receiver room viewpoint are shown in Figure 289 through Figure 300. Each figure title identifies the perspective from which the picture was taken.

Figure 289: FAC-1 installed in test window - source room.

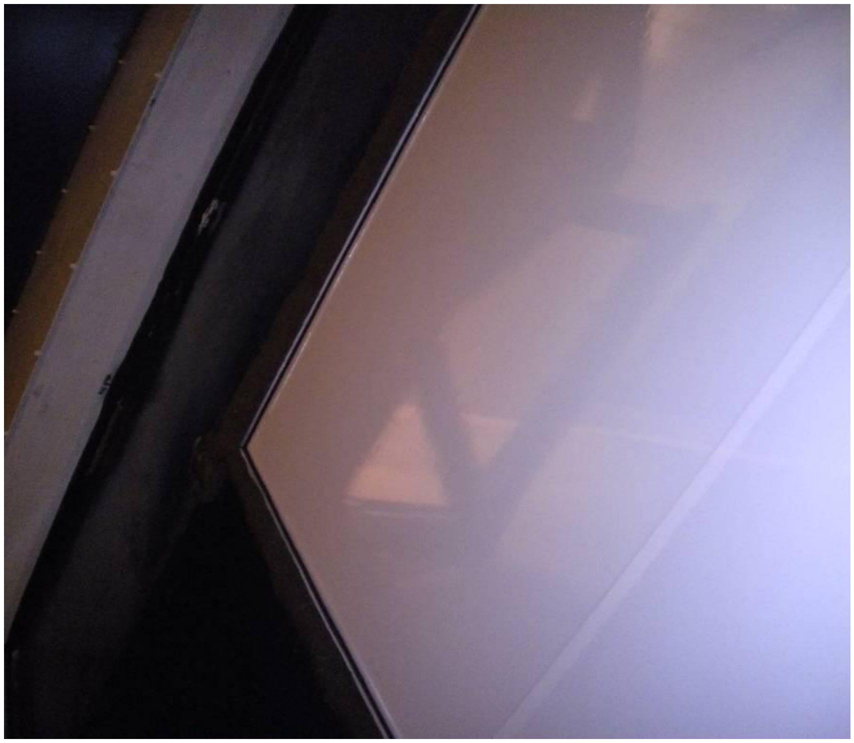

Figure 290: Close-up showing rubber seal - source room.

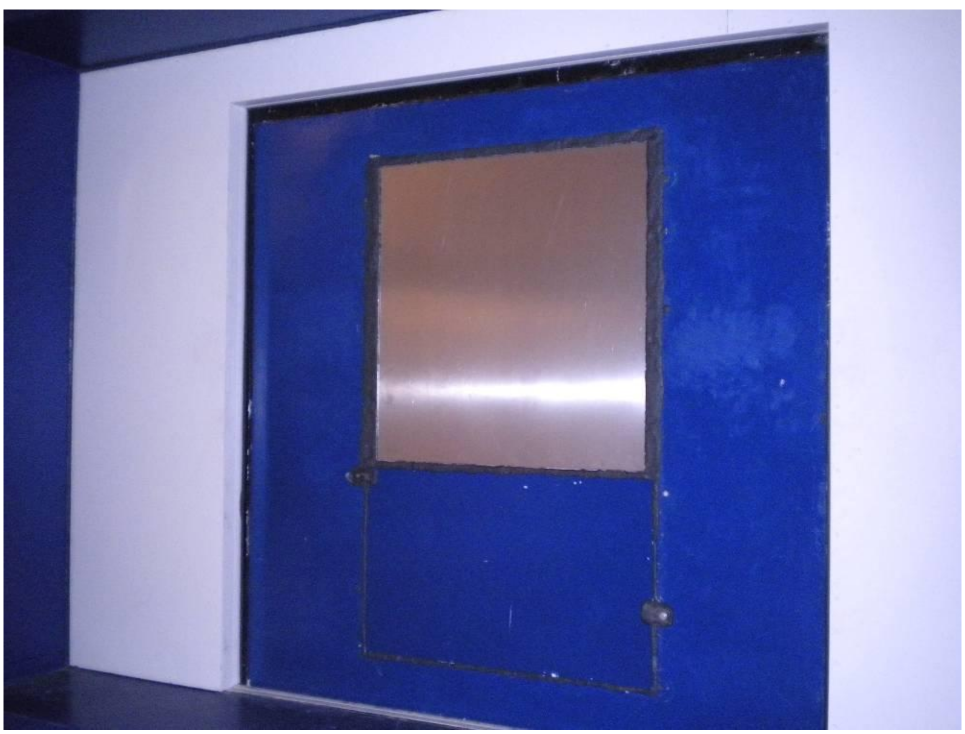

Figure 291: FAC-9 installed in test window - source room.

Figure 292: FAC-6 installed in test opening - receiver room.

Figure 293: Putty sealing panel to test window - receiver room.

Figure 294: Trim panel installed in test window - receiver room.

Figure 295: Putty sealing trim panel to test window - receiver room.

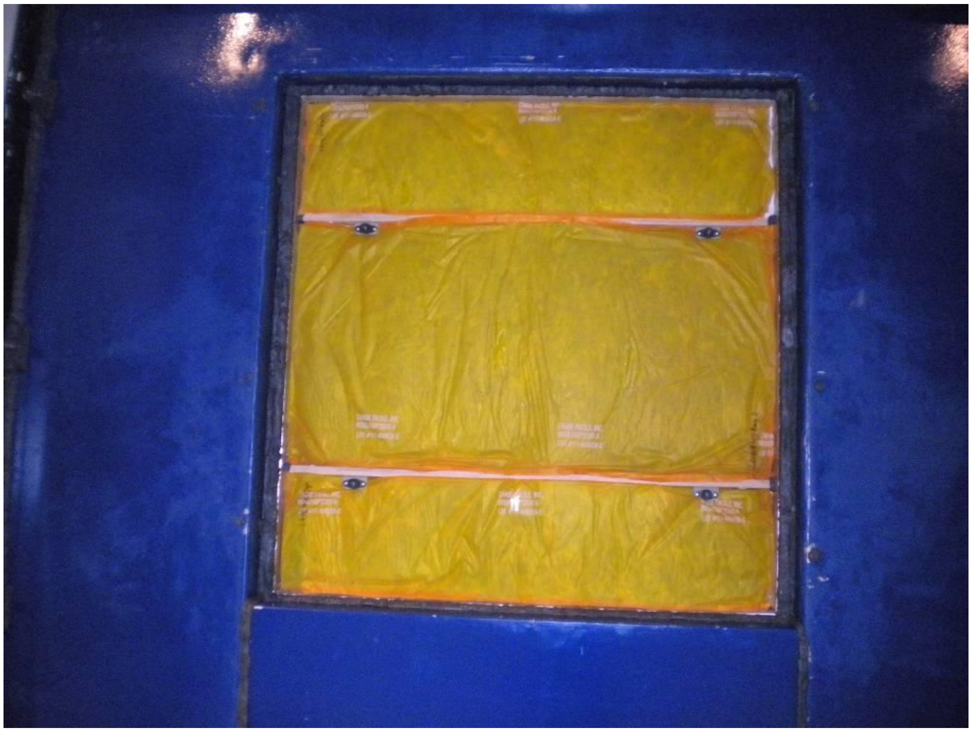

Figure 296: Between frame Fiberglass installed on panel - receiver room.

Figure 297: Damping being applied to FAC-9 - receiver room.

Figure 298: Between frame Fiberglass being applied to panel - receiver room.

Figure 299: Over-frame Nomex being applied to panel - receiver room.

Figure 300: Over-frame Fiberglass being applied to panel - receiver room.

8.6.2.3 ***Test Procedures***

Broad band noise was generated on one side of the specimen and then the space/time average of the noise was measured in 1/3 octave bands on both sides of the partition. The difference between these levels is the noise reduction (NR). In the receiving room, the rate of decay of noise was measured in each 1/3 octave band. Using these decay rates and the volume of the receiving room, the area of the specimen, and the measured NR, the transmission loss (TL) was calculated.

The ASTM E90 frequency range is from 63 to 5,000 Hertz. However, data was provided from 50 to 10,000 Hertz with uncertainties and data correction notes shown in Appendix M – Acoustic Test Data Uncertainty. The noise was produced using an electronic noise source, filters, an amplifier, and a large loudspeaker. The noise levels were measured using a continuously rotating microphone system and an analyzer. The decay rates in the receiving room were also measured utilizing the rotating microphone system. The test results include the single number ratings of Sound Transmission Class (STC), Outdoor-Indoor Transmission Class (OITC), and Airborne Sound Reduction Index (R_w). All of the data was fed into a computer which calculates and prints the transmission loss results.

8.6.2.4 ***Test Results***

8.6.2.4.1 Test Results for All Panels

TL for all 20 runs is plotted in Figure 301. The outlier is panel FAC-9a which is bare aluminum with no noise treatment. The preferred panel from previous tests was FAC-6a. Since the concept aircraft is a propeller driven aircraft, airborne noise from propeller tips impinging on the sidewall is expected to be the most dominant sound transmission into the cabin. The frequency of airborne noise from the

propellers is blade passage plus harmonics. If the propeller has 8 blades with an rpm of 1165, blade passage would be 155 hertz with the first five harmonics at 311, 466, 621, 777 and 932 hertz. This frequency range from 150 to 1,000 hertz is important to control cabin transmission loss for a comfortable cabin. The TL data quality in this frequency range is good as shown in Appendix M – Acoustic Test Data Uncertainty.

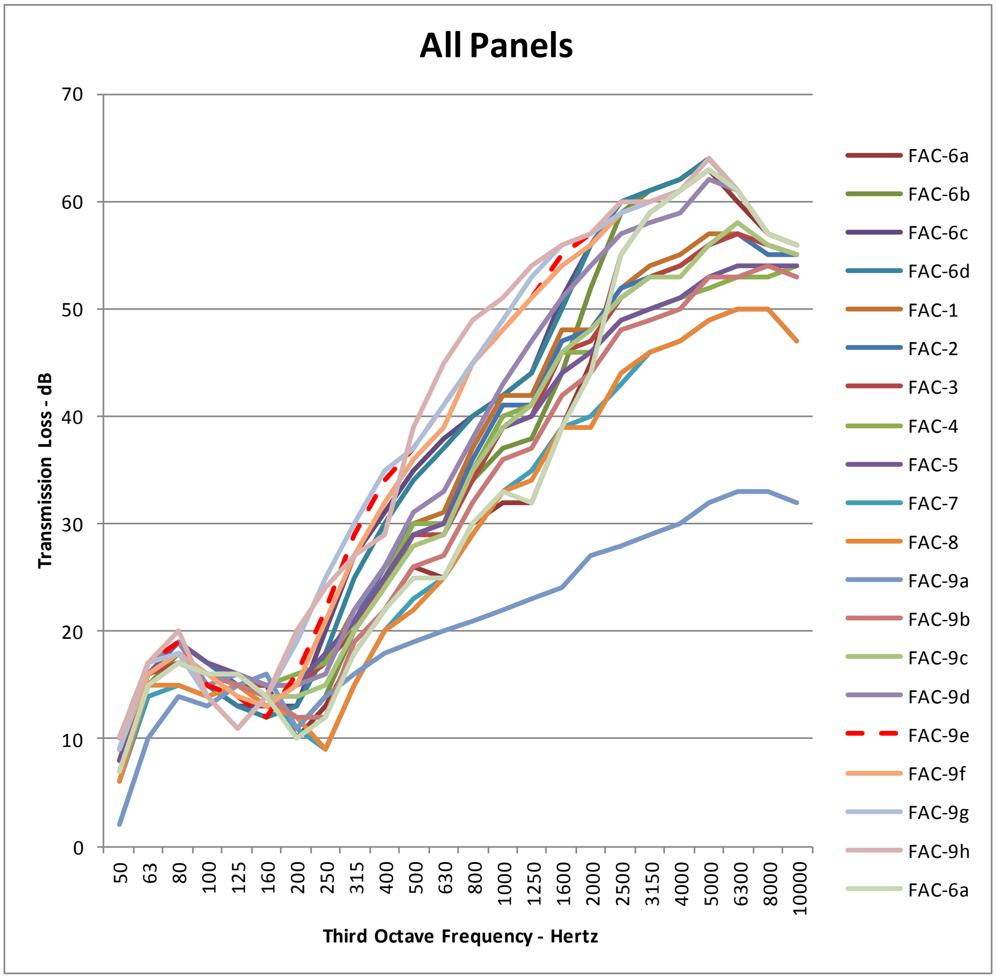

Figure 301: Results from all 20 runs.

8.6.2.4.2 Panel Transmission Loss Performance

All protective skin panels were compared to the baseline conventional aluminum panel with conventional treatment (FAC-9e) in Figure 302. A higher level of transmission loss indicates less noise transmission and a quieter cabin. FAC-6a was the preferred panel from previous test series. However, it had significantly lower transmission loss performance in the 150 to 1000 Hertz frequency range when compared to the other 5 panels tested as shown in Figure 302. In the key frequency range of 150 to 1000 Hertz, the top performing panel was FAC-1 with similar performance from FAC-2, FAC-3, FAC-4 and FAC-5 as shown in Figure 303. This is not surprising given that FAC-6 has the lowest mass as shown in Table 105 and Table 106. Also, subjectively, the stiffness was very low for the FAC-6 protective skin when compared to the other protective skins.

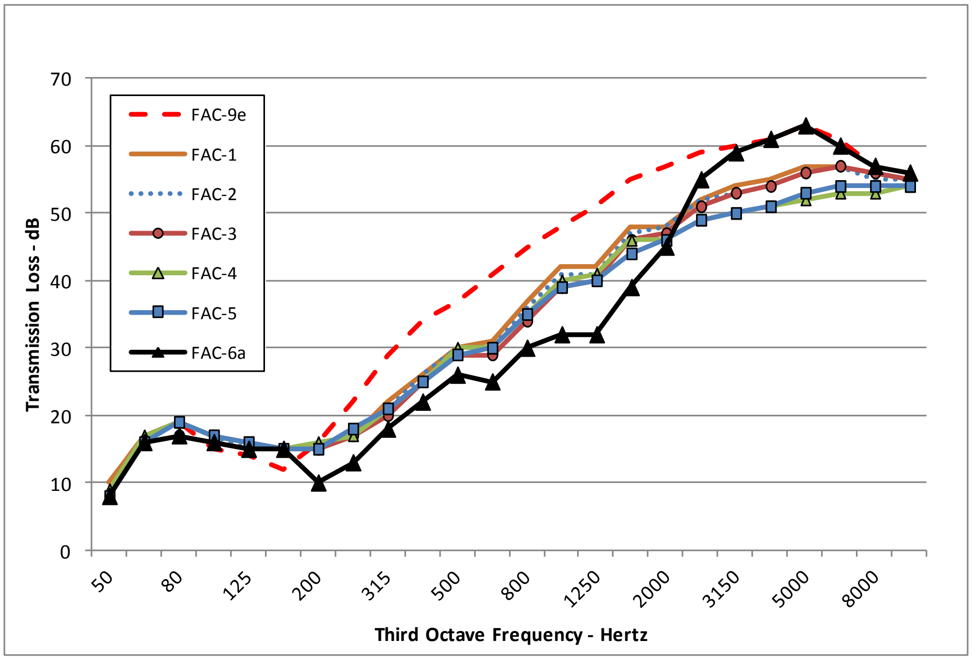

Figure 302: Protective skin panels compared to baseline panel.

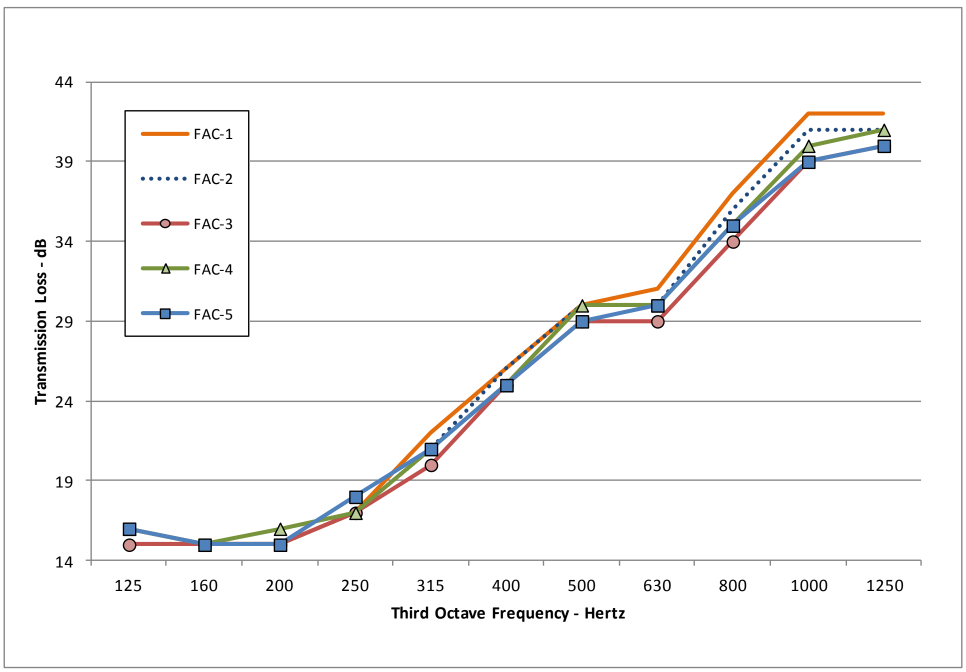

Figure 303: Best Protective Skin Panels Compared – Key Frequencies.

Table 105 - Component Weights

Component	Weight (lbs)	Areal Density (psf)	Used in Run Number
FAC-1*	21.0	1.430	5
FAC-2*	19.8	1.348	6
FAC-3*	17.9	1.219	7
FAC-4*	21.5	1.464	8
FAC-5*	20.7	1.409	9
FAC-6*	14.7	1.001	1-4,20
FAC-7*	10.8	0.735	10
FAC-8*	11.2	0.763	11
FAC-9*	14.3	0.974	12-19
Interior Trim Panel	6.5	0.443	All except 12 and 13
ADC 324 Damping	2.8	0.191	13-19
Between Frame Fiberglass	1.9	0.129	3, 4, 16, 17, 18 and 19
Nomex	1.9	0.129	2,3,15,16
Overframe Fiberglass	1.1	0.075	18
Overframe Fiberglass w/Septum	5.2	0.354	19

*Panel, Frames, Stinger & Isolators Only

Table 106 - Total Test Sample Weight and Partition Noise Metrics

Run Number	Panel Number	Tested Weight (lb)	STC	OITC	R_w
1	FAC-6a	21.2	27	20	27
2	FAC-6b	23.1	29	21	29
3	FAC-6c	25.0	31	22	33
4	FAC-6d	23.1	31	22	32
5	FAC-1	27.5	31	23	31
6	FAC-2	26.3	31	23	31
7	FAC-3	24.4	30	22	30
8	FAC-4	28.0	31	23	31
9	FAC-5	27.2	31	23	31
10	FAC-7	17.3	24	18	25
11	FAC-8	17.7	24	18	26
12	FAC-9a	14.3	22	18	22
13	FAC-9b	20.8	27	20	28
14	FAC-9c	23.6	30	22	29
15	FAC-9d	25.5	31	23	31
16	FAC-9e	27.4	33	23	34
17	FAC-9f	25.5	33	23	33
18	FAC-9g	26.6	35	23	35
19	FAC-9h	30.8	34	23	34
20	FAC-6a	21.2	27	20	27

Each panel with frames, stingers and isolators was weighed. Also, each treatment package and the trim panel were weighed separately; those weights are shown in Table 105. The total sample test weight for each run is shown in Table 106 along with Sound Transmission Class (STC), Outdoor-Indoor Transmission Class (OITC), and Airborne Sound Reduction Index (R_w).

A comparison of baseline aluminum (FAC-9b) and composite (FAC-7 & FAC-8) panels with no damping and with a trim panel is shown in Figure 304 where it can be seen that undamped aluminum has higher TL than the undamped composite panels. An aluminum panel with no damping or trim panel (FAC-9a) and a baseline aluminum panel with conventional treatment (FAC-9e) are included for reference. The transmission loss is primarily a function of weight – the composite panels FAC-7 and FAC-8 have areal densities of 0.363 and 0.371 psf, respectively while the aluminum panel FAC-9 has an areal density of 0.549 psf. The frame/stringer simulation contributed an equal 0.42 psf to all panels, and the interior trim panel added 0.443 psf.

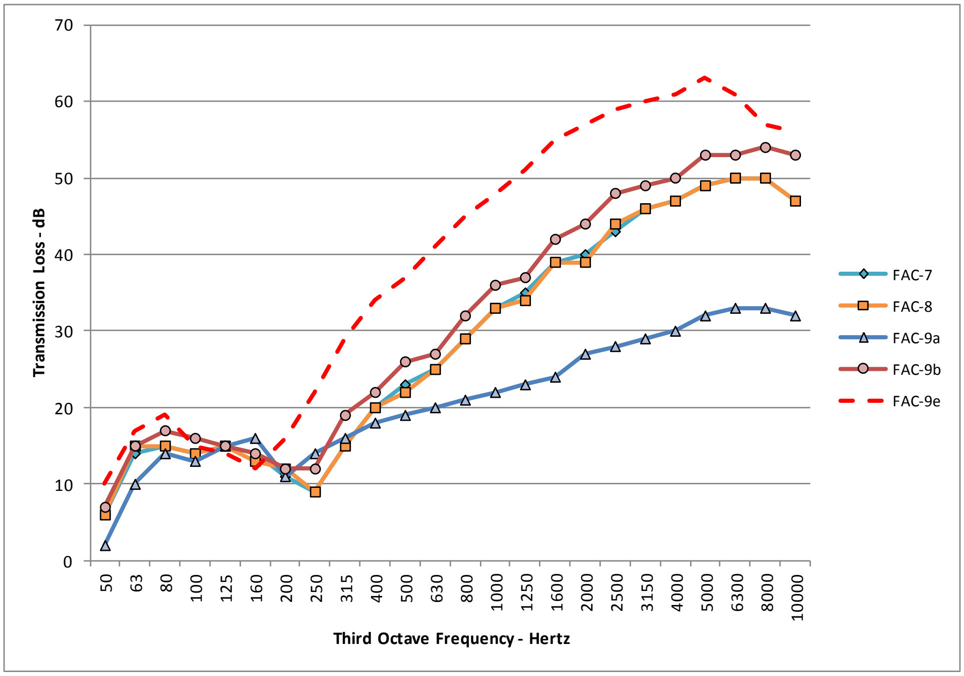

Figure 304: Undamped aluminum and composite compared.

STC is based on a noise spectrum targeting speech sounds from 125 to 4000 Hertz. R_w is similar but STC is the preferred metric for walls and partitions in the United States. The basic method for both measurements and the mathematical calculations behind both standards are similar. However, they diverge to a significant degree in the detail and in the numerical results produced. OITC utilizes a source noise spectrum that considers frequencies down to 80 Hz (aircraft/rail/truck traffic) and is weighted more to lower frequencies.

Plotting test sample weight vs. STC shows that most points lie very close to the weight vs STC trend line as shown in Figure 305. This plot can be used to assess the treatment weight effectiveness. A test sample that is above the trend line indicates a better than typical sound reduction per pound. Test samples below the trend line indicates a poorer than typical sound reduction per pound. FAC-6d, FAC-9f, and FAC-9g all have better than typical sound reduction per pound. FAC-1, FAC-4, FAC-5, and FAC-9h all had poorer than typical sound reduction per pound.

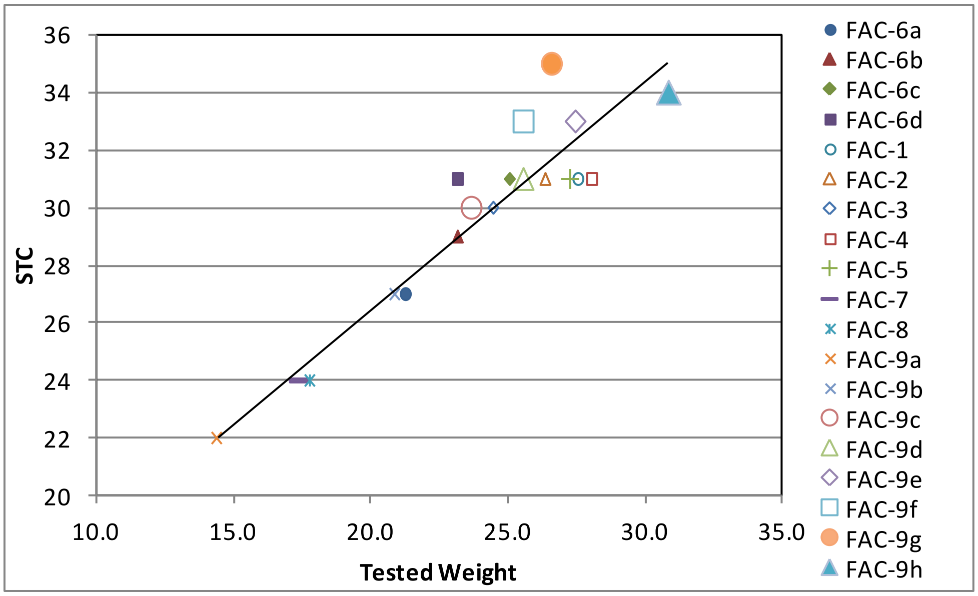

Figure 305: Treatment weight effectiveness.

8.6.2.4.3 Protective Skin Panel Treatment Options

The expectation was that at least one of the protective skin panels would have transmission loss values equal to or greater than the baseline conventional panel. This would provide a weight savings by eliminating the need for acoustic treatment. However, this is not the case. The best performing panel requires additional treatment in addition to the mass and damping provided by the protective skin in order to match the TL of the baseline conventional panel. Additional TL required in the key frequency range varies from -3 to +10 dB as shown in Figure 306. Treatments of between-frame Fiberglass (FAC-6d), over-frame Nomex (FAC6-b), and between-frame Fiberglass with over-frame Nomex (FAC-6c) were applied to FAC-1 numerically by subtracting those treatments' TL from the untreated panel (FAC-6a) TL and adding them to FAC-1 as shown in Figure 307. TL of these treatments on FAC-6 is also shown in Figure 308. The result of these comparisons is that FAC-1 requires between-frame Fiberglass to be added to perform as well as the baseline panel. Similar results are shown for panels FAC-2, FAC-3, FAC4 and FAC-5 in Figure 309. FAC-6 with the heaviest treatment of between frame fiberglass and overframe Nomex still has less TL than required to match the baseline panel as shown in Figure 310. Treatment options applied to the baseline aluminum panel are shown in Figure 311 for reference.

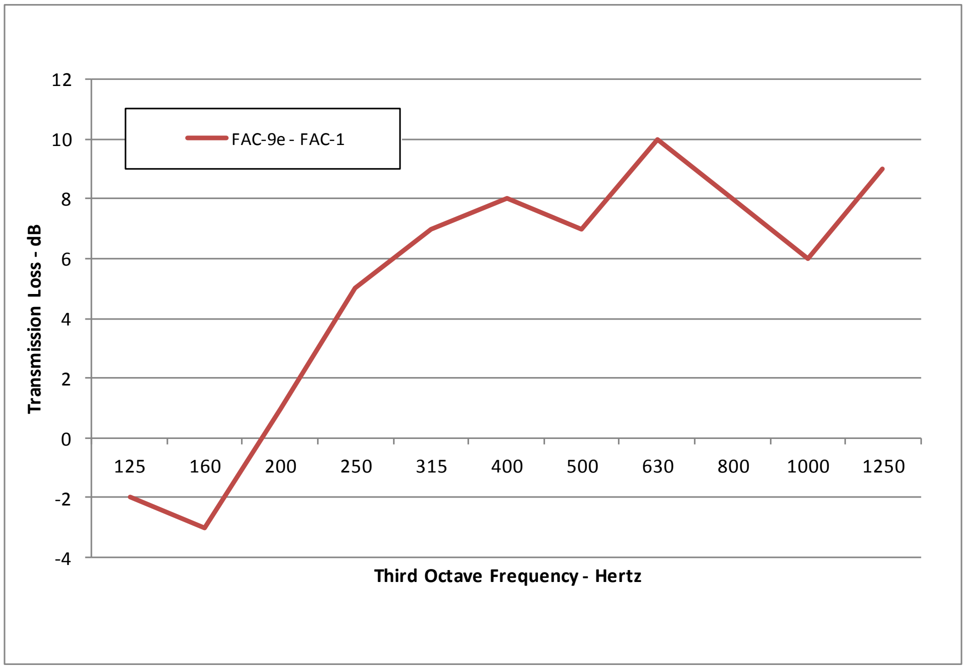

Figure 306: Additional transmission loss required from FAC-1.

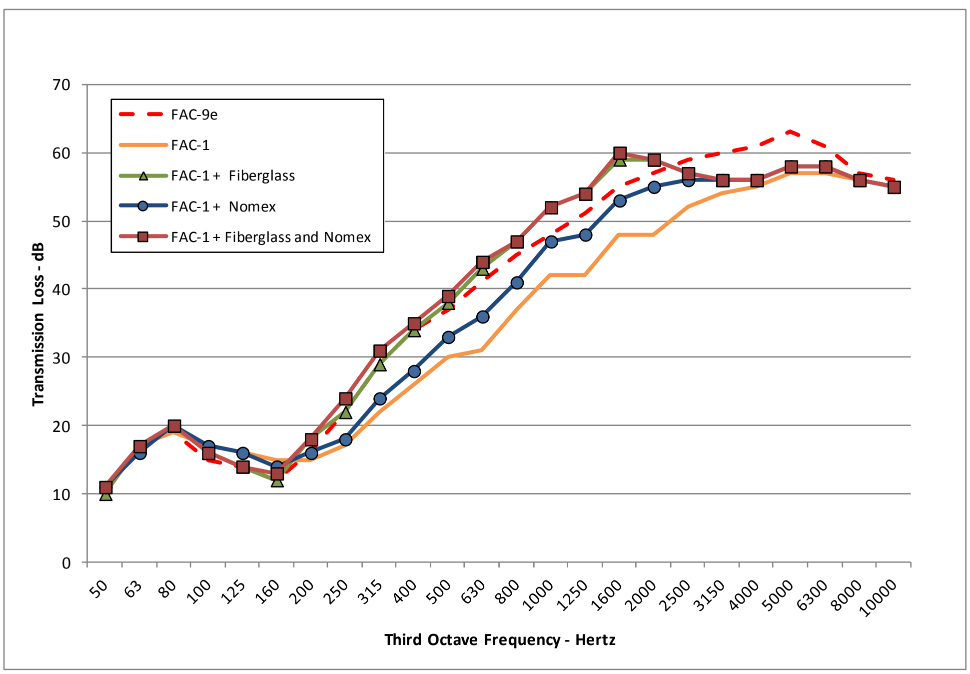

Figure 307: Best panel with treatment options.

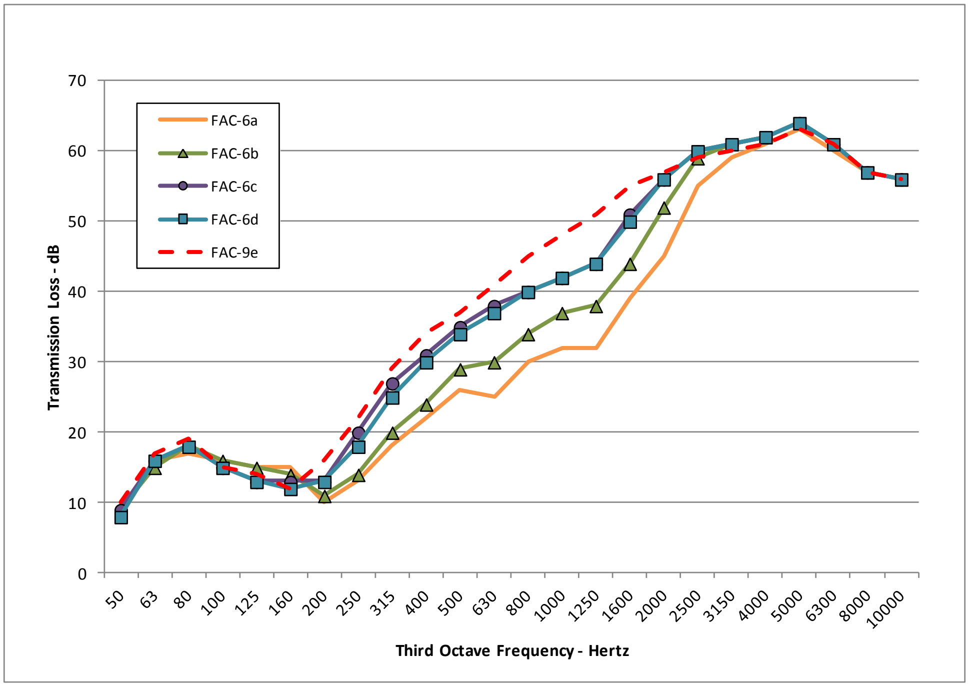

Figure 308: Preferred panel FAC-6 with treatment options.

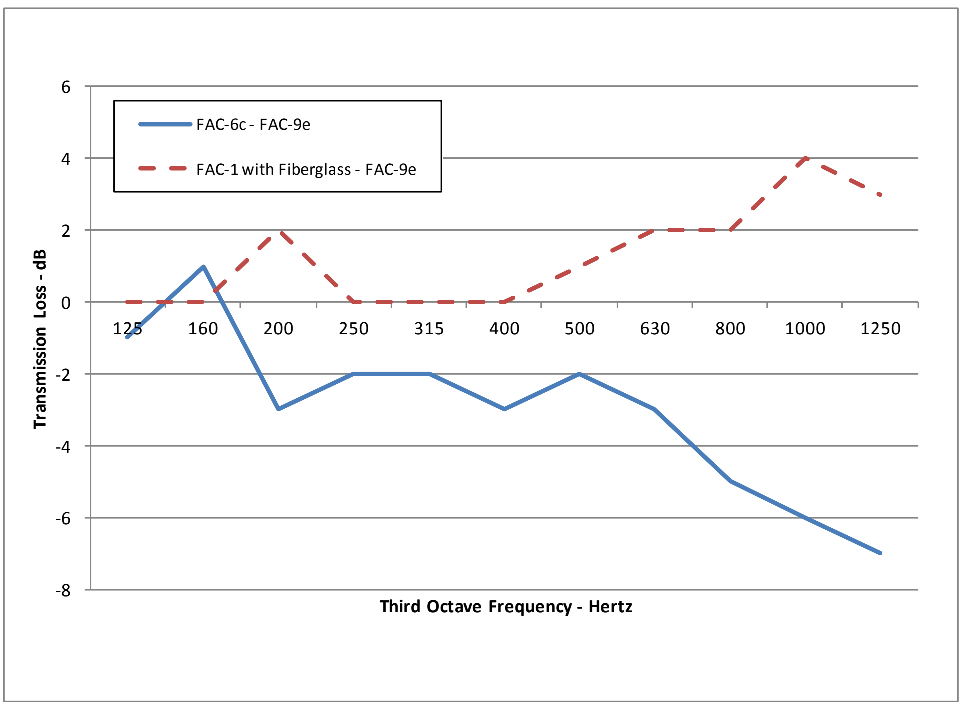

Figure 309: FAC-1 and FAC-6 with treatment options delta to baseline.

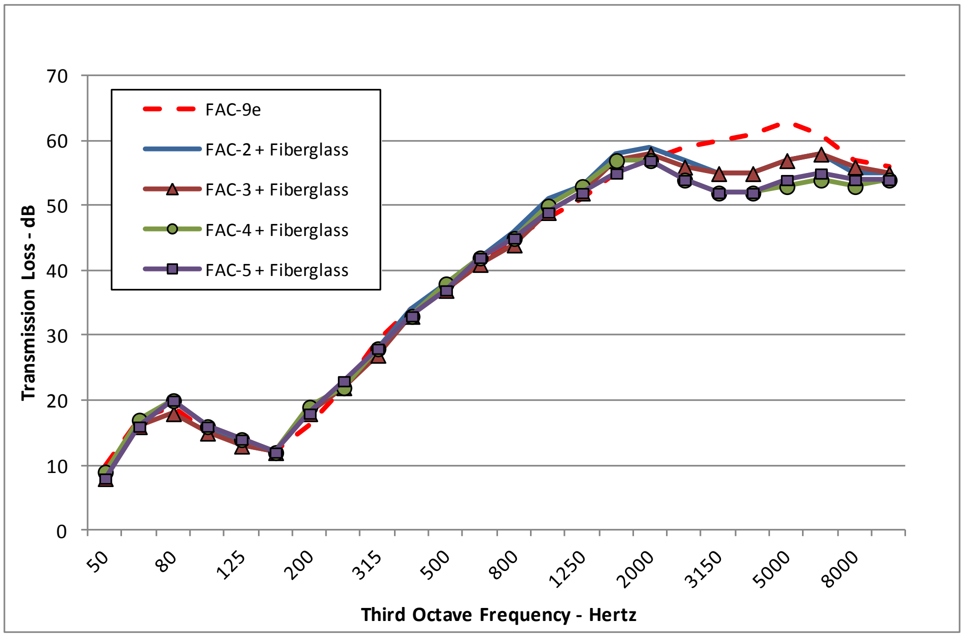

Figure 310: Other panels with treatment.

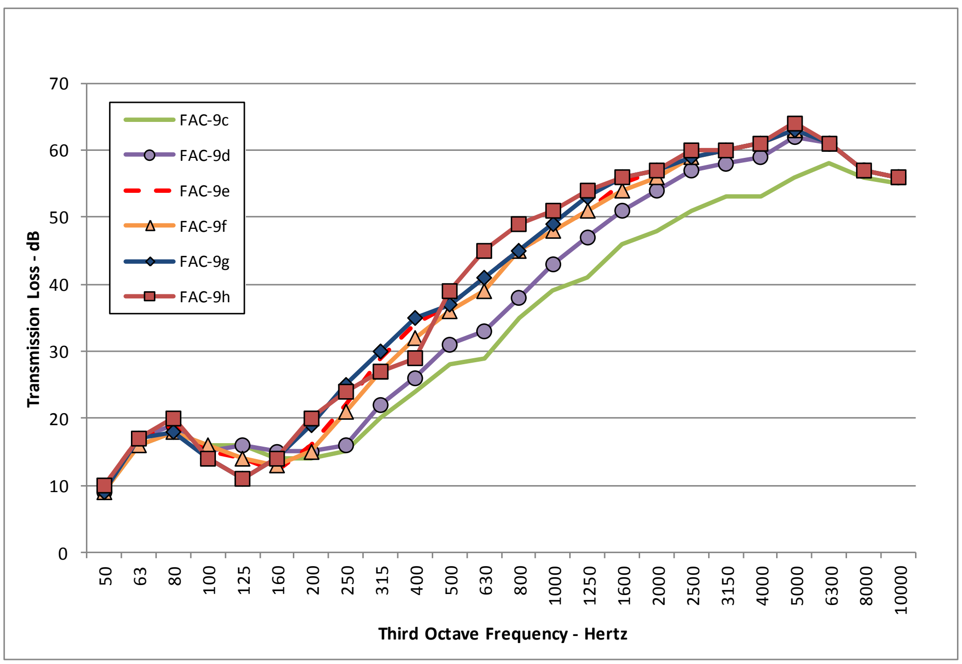

Figure 311: Baseline aluminum panel with treatment options.

8.6.2.4.4 Test Result and Test Sample Variation

The repeatability of the test was evaluated by measuring the transmission loss of FAC-6a at the beginning and end of the 20 run test sequence. The test repeatability is very good as shown in Figure 312.

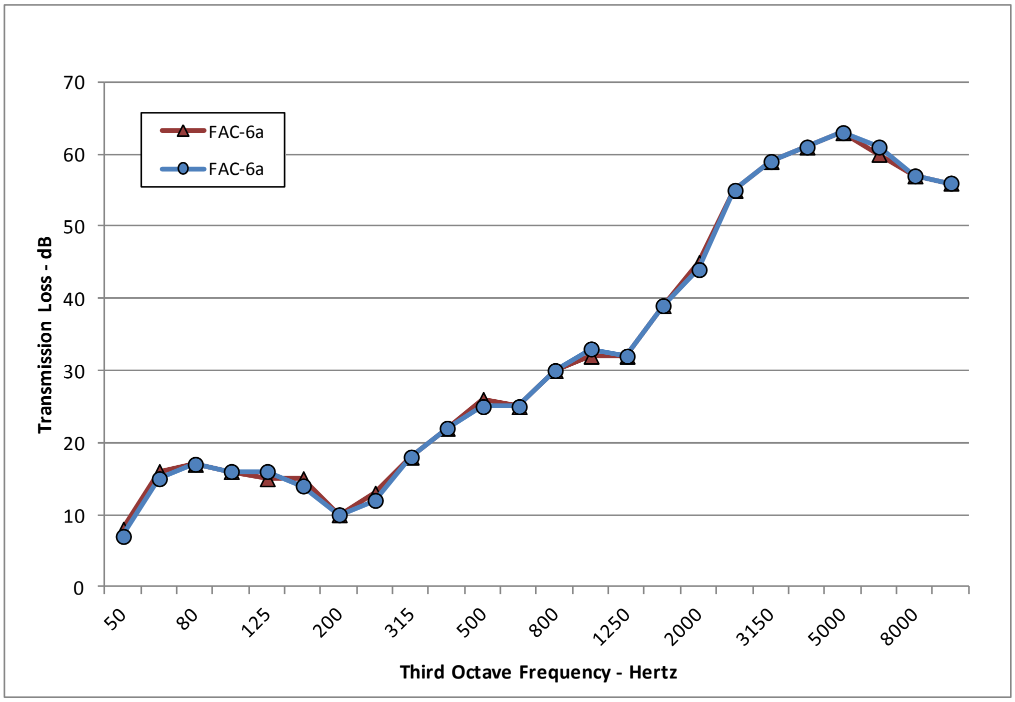

Figure 312: Repeatability of test method.

Also, due to different composite panel layup techniques used in manufacturing the base substrate panels, FAC-1, FAC-4, and FAC-5 had overlap while the others did not. To determine if this difference would affect the transmission loss test results, two additional panels were constructed without protective skins. FAC-7 was constructed without overlap and FAC-8 was constructed with overlap. Overlap did not significantly affect the results as shown in Figure 313.

A note was added to the test results for TL at 80 hertz and mostly above 2000 Hertz that states that “specimen TL too close to laboratory filler wall”. This is evident especially in the TL data above 2000 Hertz where all the results are similar. However, this is not the case for the protective skin test panels in the key frequency range of 150 to 1000 Hertz as shown in Appendix M.

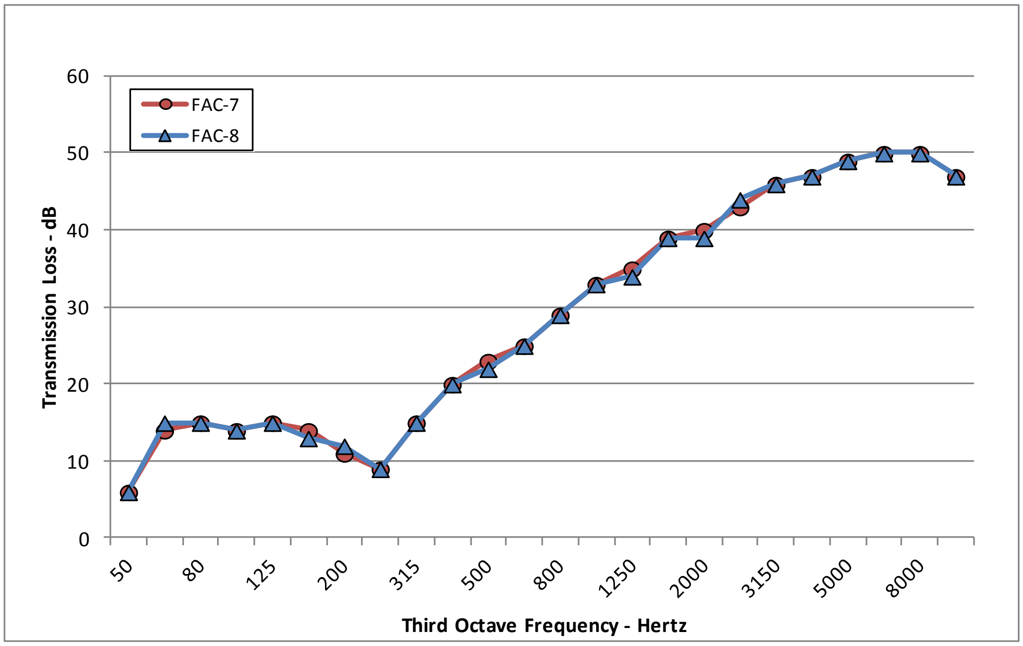

Figure 313: Effect of composite overlap.

8.6.3 Acoustics Conclusion

The test results show that FAC-1 through FAC-5 had similar transmission loss while FAC-6 had poorer TL performance in the key frequency range of 150 to 1000 Hertz. None of the protective skin panels had sufficient TL without additional treatment when compared to the baseline convention aluminum panel. However, five (FAC-1 through FAC-5) of the six protective skin panels all had similar TL to the baseline panel with only between-frame Fiberglass added. Of the five protective skin panels with similar performance, FAC-1 achieved the highest TL.

9 Conclusions

Under an N+3 Phase 2 contract from NASA's Fundamental Aeronautics Program/Subsonic Fixed Wing Project, the Cessna Aircraft Company has conducted a research program to determine the feasibility of STAR-C^2 Protective Skins for Composite Airliners. The STAR-C^2 concept was conceived to create a step change in the weight of composite aircraft structures in the 2035 timeframe. Requirements and metrics were defined, a material search was undertaken, a first generation of test articles was designed, built and tested, and using the lessons learned from those first-generation test articles, a second generation was designed, built and tested.

Based on these results, the STAR-C^2 concept does appear to be feasible (perhaps sooner than 2035). A material combination (Polydamp hydrophobic melamine impact absorbing layer with Innegra impact spreading layer) was found which appeared to both meet the main requirements and have an areal density less than the target. The impact spreading layer helps to minimize thickness and weight of the protective skin but does hurt the aesthetics and smoothing for the Polydamp panel. Innegra did a better job as the impact spreading layer than Carbon ALS for both impact depth and aesthetics. The Carbon ALS did provide adequate lightning strike protection while eliminating a painful manufacturing step with the

LDS 50-01. Eliminating paint was a significant factor in reducing the magnitude of the lightning strike problem.

There are at least five items which cast some doubt on the feasibility of the protective skins:

- There was uncertainty about the source of delamination in the Polydamp hydrophobic melamine after two 100 kAmp strikes and one 200 kAmp strike. The panel delamination could have been the result of a manufacturing flaw. Because thermographic testing did not occur after each strike, there is uncertainty about which strike caused the delamination. The delamination was closest to the second Zone 2A strike but the Zone 1A strike was twice as strong.

- There was a difference in weight and performance depending on the manufacturing process (wet layup versus VARTM). VARTM eliminated the difficulty of getting fabrics fully wetted but it also made the protective skins heavier and apparently more brittle.

- Resin which required a high cure temperature caused protective skin warpage. Reducing the cure temperature of the selected resin while increasing the cure time helped reduce the warpage but may not have given the best mechanical properties.

- The VHB tape interface caused uncertainty. The tape was heavy but could add some impact absorbing capability. The tape was an excellent way to attach the protective skin panels to the base substrate panels. Once stuck, they stayed stuck. However, lifetime of the tape in actual application is uncertain.

- There were questions about long-term durability of the protective skins based on experience with handling damage. Dents in the protective skin, tears in the aesthetic film, and other “road rash” left some doubt about long-term durability.

The research project also identified some aspects of the protective skins which were not successful:

- No material combination was found which would hide fasteners, doublers, and wires. Some combinations were better than others, but none was perfect. The business jet aesthetics requirements may be too stringent for an airliner.

- Another unsuccessful aspect of the protective skins was acoustics. No special action was taken to try to minimize noise reduction through the protective skins. The transmission loss was all about weight – where heavier was better.

- A simple manufacturing solution was not identified. To be successful the protective skins need to be easy to make for practical airplane shapes. The aesthetic film needs to be applied with no wrinkles or bubbles in a manner that does not interrupt the natural laminar flow facilitated by the skins. The seams need to look good and function as a moisture block. Closely associated with manufacturing process is the repair process.

10 Recommendations

Cessna Aircraft Company has expertise and core competencies in material qualification, purchase, and usage. The choices of materials to demonstrate the feasibility of the STAR-C^2 concept was based on the

materials more than on the properties of the materials and how they would be combined. The next steps need to be down a level at the material chemistry and material combination level. For example, a resin with strong mechanical properties resulting from a room temperature cure would be helpful. Room temperature cure resins currently exist; the question is their mechanical properties when cured. A resin tailoring process for VARTM to make sure the Soric LRC and Innegra are uniformly wetted but not so resin infused that they become brittle could be very useful.

A very useful step (with near-term application in current materials) is the integration of the ALS (Aluminum Lightning Strike) system in Innegra. Innegra, like carbon, is a woven fiber. The inclusion of the thin aluminum wire should be achievable. Cessna had the opportunity to suggest this to Innegra Research and Development personnel. They (and their fabric weaving company) liked the idea and thought it was achievable. An added benefit is that there is no adverse chemical reaction between Innegra and aluminum like there is between carbon and aluminum. For STAR-C^2 protective skins, the existence of an Innegra ALS system would eliminate a manufacturing step with a very hard-to-handle material.

The proverbial recommendation which no research project can be without is to reduce weight while maintaining mechanical properties. The closer the STAR-C^2 protective skins to the target (or even below), the more likely the fuel and weight savings can be realized.

The final recommendation is much more global. Aircraft manufacturers are just becoming comfortable with certification requirements for traditional composite materials. It took a lot of work to get to this point. STAR-C^2 protective skins change the paradigm. Research is necessary to demonstrate what the requirements must be, what the properties of the protective skins must be, and what means of showing compliance may be used to demonstrate that an aircraft with STAR-C^2 protective skins is safe. This is the proverbial chicken and egg problem. Without a path to show compliance, manufacturers will not invest in the development of aircraft with protective skins. Without manufacturers with a need to show compliance, certification regulations will not be developed. The definition of the next phase of work on STAR-C^2 protective skins should include both the development of the skins and the certification requirements.

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Appendix A -
Links to Information About Materials Used

Table 1 - Links to Information About Asthetic Materials

Aesthetic Layers	Information Links
Integument Film	http://integument.com/
3m 5004	http://solutions.3m.com/wps/portal/3M/en_US/Aerospace/Aircraft/Prod_Info/Prod_Catalog/?PC_7_RJH9U5230GE3E02LECIE20SOG5_nid=60TTNMF70Rbe90657JDCX3gl
Halar	multiple commercial sources, http://www.welchfluorocarbon.com/techdata.htm, http://www.cshyde.com/Films/halarfilm.htm
Aptiv	http://www.victrex.com/en/products/aptiv-films/aptiv-films.php
Kapton	http://cshyde.thomasnet.com/viewitems/films/kapton-polyimide-film-type-hn?&bc=100|1002

Table 2 - Links to Information about Impact Materials

Energy Absorbing	Information Links
10 pcf PU core, FR-4500 or FR-7100	http://www.generalplastics.com/solutions/product-lines/rigid-foams/
20 pcf PU core, , FR-4500 or FR-7100	http://www.generalplastics.com/solutions/product-lines/rigid-foams/
30 pcf PU core, , FR-4500 or FR-7100	http://www.generalplastics.com/solutions/product-lines/rigid-foams/
4 pcf non-metallic honeycomb core	http://hexcel.com/Resources/DataSheets/Honeycomb-Data-Sheets/HRH_10_us.pdf
3 pcf metallic honeycomb core	http://hexcel.com/Resources/DataSheets/Honeycomb-Data-Sheets/CR3_us.pdf
6 pcf metallic honeycomb core	http://hexcel.com/Resources/DataSheets/Honeycomb-Data-Sheets/CR3_us.pdf
9 pcf metallic honeycomb core	http://hexcel.com/Resources/DataSheets/Honeycomb-Data-Sheets/CR3_us.pdf
Soric LRC	http://lantor.nl/index.php/id_pagina/29359/product-data-sheets.html
Soric XF	http://lantor.nl/index.php/id_pagina/29359/product-data-sheets.html
Polydamp with metallized PEEK	http://www.polytechinc.com/products/aircrafts.php

Table 3 - Links to Information about Impact Spreading Materials

Impact Spreading Layer	Information Links
Innegra	http://www.innegrity.com/innegra-s.php
Tegris	http://www.milliken2.com/MFT/MFThtml.nsf/page/home.htm
Aluminum	common industry material
Carbon Epoxy	common industry material

Table 4 - Links to Information about Lightning Strike Materials

Lightning Strike Protection	Information Links
Integument with lightning strike protection	http://integument.com/
0.016 psf expanded aluminum foil	several sources, http://www.dexmet.com/Expanded-Metals.html or http://www.astrosealproducts.com
0.029 psf expanded copper foil	several sources, http://www.dexmet.com/Expanded-Metals.html or http://www.astrosealproducts.com
LDS 40-03(N) 0.0016 psf nickel coated copper	http://www.lightningdiversion.com/Products.htm
LDS 50-01 0.007 psf aluminum	http://www.lightningdiversion.com/Products.htm
Proprietary spray material	N/A

Appendix B -
First-Generation Base Panel Inspection Results

Table B-1 - First-Generation Base Panel Weights and Dimensions (1 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
1	1.33	24.20	24.20	24.20	24.20	24.15	24.19	0.0224	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.329
2	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	0.330
3	1.32	24.05	24.00	24.00	24.00	24.00	24.01	0.0224	24.15	24.10	24.15	24.15	24.20	24.15	0.0354	0.328
4	1.32	24.10	24.00	24.00	24.00	24.00	24.02	0.0447	24.15	24.15	24.15	24.15	24.20	24.16	0.0224	0.328
5	1.32	24.00	24.00	24.00	24.00	24.05	24.01	0.0224	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.328
6	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.329
7	1.32	24.05	24.05	24.10	24.10	24.15	24.09	0.0418	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.327
8	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	24.15	24.15	24.15	24.15	24.15	24.15	0.0000	0.327
9	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	0.329
10	1.35	24.25	24.20	24.20	24.20	24.20	24.21	0.0224	24.20	24.20	24.20	24.20	24.15	24.19	0.0224	0.332
11	1.33	24.00	24.00	24.05	24.10	24.10	24.05	0.0500	24.30	24.30	24.30	24.25	24.25	24.28	0.0274	0.328
12	1.30	23.95	23.95	23.95	24.00	24.00	23.97	0.0274	24.00	24.00	24.00	24.05	24.00	24.01	0.0224	0.325
13	1.32	24.10	24.10	24.10	24.15	24.10	24.11	0.0224	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.326
14	1.33	24.10	24.10	24.10	24.10	24.05	24.09	0.0224	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.329
15	1.32	24.00	24.00	24.00	24.05	24.10	24.03	0.0447	24.15	24.15	24.15	24.20	24.20	24.17	0.0274	0.327
16	1.32	24.05	24.05	24.05	24.10	24.10	24.07	0.0274	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.326
17	1.36	24.20	24.20	24.20	24.20	24.10	24.18	0.0447	24.20	24.20	24.25	24.25	24.30	24.24	0.0418	0.334
18	1.34	24.10	24.10	24.10	24.05	24.00	24.07	0.0447	24.25	24.25	24.25	24.30	24.30	24.27	0.0274	0.330
19	1.30	24.05	24.05	24.10	24.10	24.10	24.08	0.0274	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	0.324
20	1.28	23.75	23.75	23.75	23.75	23.80	23.76	0.0224	24.00	23.95	23.00	23.90	23.90	23.75	0.4213	0.327
21	1.30	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	24.05	24.05	24.00	24.00	24.00	24.02	0.0274	0.325
22	1.34	24.20	24.20	24.25	24.25	24.25	24.23	0.0274	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.329
23	1.32	24.20	24.15	24.15	24.20	24.20	24.18	0.0274	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.325
24	1.34	24.10	24.15	24.20	24.20	24.15	24.16	0.0418	24.15	24.15	24.15	24.20	24.20	24.17	0.0274	0.330
25	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	24.15	24.15	24.15	24.15	24.15	24.15	0.0000	0.327

Table B-1 - First-Generation Base Panel Weights and Dimensions (2 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
26	1.34	24.15	24.15	24.15	24.10	24.10	24.13	0.0274	24.15	24.15	24.15	24.10	24.10	24.13	0.0274	0.331
27	1.33	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	24.00	24.00	24.05	24.00	24.00	24.01	0.0224	0.330
28	1.32	24.00	24.00	24.05	24.05	24.05	24.03	0.0274	24.25	24.25	24.30	24.20	24.15	24.23	0.0570	0.326
29		24.00	24.05	24.10	24.10	24.00	24.05	0.0500	23.95	23.95	23.95	23.90	23.90	23.93	0.0274	
30	1.32	24.10	24.10	24.10	24.10	24.15	24.11	0.0224	24.15	24.15	24.15	24.15	24.20	24.16	0.0224	0.326
31	1.32	24.10	24.10	24.10	24.10	24.15	24.11	0.0224	24.10	24.10	24.10	24.10	24.15	24.11	0.0224	0.327
32	1.34	24.15	24.15	24.10	24.10	24.10	24.12	0.0274	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.331
33	1.32	24.10	24.10	24.10	24.00	24.00	24.06	0.0548	24.01	24.00	24.00	24.00	24.00	24.00	0.0022	0.329
34	1.33	24.10	24.10	24.10	24.10	24.20	24.12	0.0447	24.05	24.05	24.05	24.00	24.00	24.03	0.0274	0.330
35	1.33	24.20	24.20	24.20	24.20	24.25	24.21	0.0224	24.05	24.05	24.05	24.05	24.05	24.05	0.0000	0.329
36	1.30	24.10	24.10	24.05	24.00	24.00	24.05	0.0500	24.00	24.00	24.00	24.00	24.00	24.00	0.0000	0.324
37	1.30	24.00	24.00	24.05	24.05	24.05	24.03	0.0274	24.05	24.05	24.05	24.05	24.05	24.05	0.0000	0.324
38	1.32	24.00	24.00	24.00	24.00	23.95	23.99	0.0224	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.327
39	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	24.15	24.15	24.15	24.20	24.20	24.17	0.0274	0.326
40	1.34	24.15	24.15	24.15	24.15	24.20	24.16	0.0224	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.331
41	1.33	24.20	24.15	24.15	24.15	24.20	24.17	0.0274	24.10	24.10	24.05	24.00	24.00	24.05	0.0500	0.329
42	1.34	24.20	24.20	24.25	24.20	24.20	24.21	0.0224	24.15	24.15	24.20	24.20	24.20	24.18	0.0274	0.330
43	1.34	24.20	24.20	24.20	24.15	24.20	24.19	0.0224	24.20	24.15	24.10	24.10	24.10	24.13	0.0447	0.331
44	1.30	24.15	24.15	24.10	24.10	24.15	24.13	0.0274	24.10	24.00	24.00	24.00	24.00	24.02	0.0447	0.323
45		23.95	23.90	24.00	24.00	24.05	23.98	0.0570	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	
46	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	24.20	24.15	24.15	24.15	24.20	24.17	0.0274	0.326
47	1.32	24.10	24.05	24.05	24.05	24.00	24.05	0.0354	24.15	24.15	24.15	24.10	24.15	24.14	0.0224	0.327
48	1.32	24.10	24.10	24.10	24.10	24.15	24.11	0.0224	24.10	24.10	24.10	24.10	24.10	24.10	0.0000	0.327
49	1.36	24.25	24.25	24.25	24.25	24.20	24.24	0.0224	24.30	24.30	24.30	24.30	24.25	24.29	0.0224	0.333
50	1.34	24.15	24.15	24.10	24.05	24.05	24.10	0.0500	24.20	24.20	24.20	24.20	24.20	24.20	0.0000	0.331

Table B-1 - First-Generation Base Panel Weights and Dimensions (3 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
51		23.95	23.95	23.90	23.90	23.90	23.92	0.03	24.05	24.05	24.05	24.10	24.10	24.07	0.03	
52	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.15	24.15	24.15	24.15	24.15	24.15	0.00	0.330
53	1.34	24.20	24.20	24.20	24.15	24.10	24.17	0.04	24.15	24.15	24.15	24.15	24.15	24.15	0.00	0.331
54	1.33	24.10	24.10	24.00	24.00	24.00	24.04	0.05	24.10	24.05	24.10	24.00	24.00	24.05	0.05	0.331
55	1.30	24.00	24.05	24.05	24.05	24.10	24.05	0.04	23.90	23.95	24.00	23.95	24.00	23.96	0.04	0.325
56	1.32	24.00	24.05	24.05	24.00	24.00	24.02	0.03	24.15	24.10	24.10	24.15	24.15	24.13	0.03	0.328
57	1.32	24.20	24.15	24.15	24.10	24.10	24.14	0.04	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.328
58	1.34	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.331
59	1.34	24.05	24.05	24.05	24.05	24.05	24.05	0.00	24.00	24.05	24.05	24.00	24.00	24.02	0.03	0.334
60	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.10	24.10	24.15	24.10	24.10	24.11	0.02	0.331
61	1.34	24.20	24.15	24.15	24.15	24.15	24.16	0.02	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
62	1.32	24.10	24.05	24.1	24.10	24.10	24.09	0.02	24.10	24.10	24.05	24.00	24.05	24.06	0.04	0.328
63	1.34	24.10	24.15	24.15	24.15	24.15	24.14	0.02	24.15	24.15	24.15	24.15	24.20	24.16	0.02	0.331
64	1.32	24.20	24.15	24.15	24.15	24.15	24.16	0.02	24.00	24.05	24.00	24.05	24.05	24.03	0.03	0.327
65	1.34	24.15	24.20	24.15	24.15	24.15	24.16	0.02	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
66	1.32	24.10	24.10	24.1	24.05	24.05	24.08	0.03	24.00	24.00	24.05	24.05	24.00	24.02	0.03	0.329
67	1.32	24.20	24.20	24.2	24.20	24.15	24.19	0.02	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.327
68	1.32	24.15	24.10	24.1	24.05	24.00	24.08	0.06	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.328
69	1.33	24.10	24.10	24.1	24.15	24.20	24.13	0.04	24.20	24.20	24.20	24.20	24.25	24.21	0.02	0.328
70	1.32	24.00	24.10	24.1	24.10	24.10	24.08	0.04	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.328
71	1.34	24.20	24.10	24.20	24.10	24.10	24.14	0.05	24.20	24.15	24.20	24.20	24.20	24.19	0.02	0.330
72	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.20	24.15	24.15	24.15	24.15	24.16	0.02	0.326
73	1.30	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.10	24.05	24.00	24.00	24.00	24.03	0.04	0.323
74	1.32	24.20	24.15	24.10	24.10	24.15	24.14	0.04	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.325
75		24.20	24.20	24.15	24.15	24.15	24.17	0.03	23.90	23.95	24.00	24.00	23.95	23.96	0.04	

Table B-1 - First-Generation Base Panel Weights and Dimensions (4 of 8)

	0.01 lbs	0.05 in													lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
76	1.30	24.15	24.10	24.10	24.10	24.10	24.11	0.02	23.95	24.00	24.00	24.00	24.00	23.99	0.02	0.324
77	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.00	24.00	24.00	24.00	24.05	24.01	0.02	0.328
78	1.30	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.20	24.15	24.10	24.10	24.10	24.13	0.04	0.323
79	1.34	24.10	24.20	24.20	24.20	24.20	24.18	0.04	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.331
80	1.34	24.10	24.10	24.15	24.15	24.10	24.12	0.03	24.30	24.25	24.30	24.25	24.25	24.27	0.03	0.330
81	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.10	24.05	24.05	24.05	24.00	24.05	0.04	0.328
82	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.329
83	1.34	24.20	24.15	24.15	24.15	24.15	24.16	0.02	24.15	24.15	24.15	24.20	24.20	24.17	0.03	0.330
84	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.331
85	1.32	24.05	24.10	24.10	24.10	24.15	24.10	0.04	24.00	24.00	24.00	24.05	24.00	24.01	0.02	0.328
86	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.10	24.00	24.05	24.05	24.00	24.04	0.04	0.329
87	1.32	24.20	24.15	24.20	24.10	24.10	24.15	0.05	24.00	24.00	24.00	24.00	24.05	24.01	0.02	0.328
88		24.00	23.95	24.00	24.00	24.00	23.99	0.02	24.00	23.95	23.95	23.95	24.00	23.97	0.03	
89	1.34	24.05	24.00	24.00	24.00	24.05	24.02	0.03	24.20	24.15	24.15	24.10	24.20	24.16	0.04	0.333
90	1.34	24.25	24.25	24.20	24.20	24.20	24.22	0.03	24.25	24.25	24.25	24.20	24.25	24.24	0.02	0.329
91	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.00	24.00	24.05	24.01	0.02	0.330
92	1.34	24.25	24.25	24.20	24.20	24.25	24.23	0.03	24.00	24.00	24.00	24.10	24.10	24.04	0.05	0.331
93	1.34	24.10	24.10	24.05	24.00	24.05	24.06	0.04	24.20	24.15	24.15	24.10	24.10	24.14	0.04	0.332
94	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.05	24.05	24.05	24.05	24.05	24.05	0.00	0.332
95	1.32	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.00	23.95	23.95	24.00	24.00	23.98	0.03	0.328
96	1.34	24.10	24.15	24.15	24.15	24.20	24.15	0.04	24.20	24.20	24.20	24.15	24.20	24.19	0.02	0.330
97	1.32	24.25	24.20	24.20	24.20	24.10	24.19	0.05	24.00	24.10	24.10	24.05	24.05	24.06	0.04	0.327
98	1.32	24.21	24.10	24.15	24.10	24.10	24.13	0.05	24.15	24.15	24.15	24.10	24.15	24.14	0.02	0.326
99	1.31	24.10	24.10	24.15	24.10	24.10	24.11	0.02	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.326
100	1.30	24.00	24.00	24.05	24.05	24.05	24.03	0.03	24.10	24.15	24.15	24.15	24.15	24.14	0.02	0.323

Table B-1 - First-Generation Base Panel Weights and Dimensions (5 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
101	1.34	24.25	24.20	24.20	24.20	24.20	24.21	0.02	24.25	24.25	24.25	24.20	24.20	24.23	0.03	0.329
102		24.00	24.00	24.00	24.00	23.95	23.99	0.02	23.90	23.90	23.90	23.90	23.85	23.89	0.02	
103	1.34	24.20	24.20	24.25	24.25	24.25	24.23	0.03	24.25	24.25	24.25	24.20	24.20	24.23	0.03	0.329
104	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.15	24.15	24.15	24.10	24.10	24.13	0.03	0.330
105	1.34	24.15	24.15	24.20	24.20	24.15	24.17	0.03	24.05	24.05	24.05	24.05	24.05	24.05	0.00	0.332
106	1.32	24.15	24.15	24.20	24.15	24.15	24.16	0.02	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.326
107	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.10	24.15	24.15	24.15	24.10	24.13	0.03	0.330
108	1.32	24.10	24.15	24.15	24.15	24.20	24.15	0.04	23.95	23.95	23.95	23.95	23.95	23.95	0.00	0.329
109	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.00	24.00	24.00	24.05	24.00	24.01	0.02	0.332
110	1.32	24.15	24.15	24.15	24.10	24.10	24.13	0.03	24.20	24.20	24.20	24.15	24.10	24.17	0.04	0.326
111	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.326
112	1.34	24.15	24.15	24.20	24.20	24.20	24.18	0.03	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
113	1.28	23.90	23.90	23.85	23.85	23.80	23.86	0.04	23.80	23.80	23.80	23.80	23.80	23.80	0.00	0.325
114	1.30	23.90	23.95	24.00	24.00	24.00	23.97	0.04	23.95	24.00	24.00	24.00	24.10	24.01	0.05	0.325
115	1.32	24.20	24.20	24.20	24.15	24.15	24.18	0.03	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.328
116	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.00	24.00	23.95	23.95	23.95	23.97	0.03	0.329
117	1.32	24.10	24.15	24.15	24.15	24.15	24.14	0.02	23.90	23.95	23.95	23.95	23.95	23.94	0.02	0.329
118	1.32	24.10	24.10	24.10	24.05	24.05	24.08	0.03	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.329
119	1.32	24.10	24.10	24.05	24.00	24.05	24.06	0.04	24.15	24.15	24.15	24.15	24.15	24.15	0.00	0.327
120	1.32	24.05	24.10	24.10	24.05	24.00	24.06	0.04	24.15	24.20	24.20	24.20	24.20	24.19	0.02	0.327
121	1.32	24.10	24.15	24.15	24.15	24.15	24.14	0.02	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.328
122	1.34	24.10	24.15	24.20	24.20	24.20	24.17	0.04	24.20	24.20	24.15	24.15	24.15	24.17	0.03	0.330
123	1.35	24.20	24.25	24.20	24.20	24.20	24.21	0.02	24.25	24.25	24.25	24.25	24.30	24.26	0.02	0.331
124	1.34	24.20	24.20	24.15	24.10	24.05	24.14	0.07	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.332
125	1.34	24.15	24.20	24.20	24.15	24.10	24.16	0.04	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330

Table B-1 - First-Generation Base Panel Weights and Dimensions (6 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
126	1.32	24.10	24.10	24.15	24.10	24.10	24.11	0.02	24.10	24.10	24.10	24.05	24.05	24.08	0.03	0.327
127	1.34	24.15	24.15	24.15	24.15	24.15	24.15	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
128	1.32	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.326
129	1.32	24.15	24.20	24.20	24.15	24.15	24.17	0.03	24.15	24.15	24.20	24.15	24.15	24.16	0.02	0.326
130	1.32	24.15	24.15	24.15	24.15	24.15	24.15	0.00	23.95	24.00	24.05	24.00	24.10	24.02	0.06	0.328
131	1.32	24.15	24.15	24.15	24.10	24.10	24.13	0.03	24.10	24.10	24.10	24.05	24.05	24.08	0.03	0.327
132	1.30	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.00	24.00	24.05	24.00	24.05	24.02	0.03	0.323
133	1.30	24.15	24.15	24.15	24.15	24.15	24.15	0.00	24.00	24.00	24.05	24.00	24.00	24.01	0.02	0.323
134	1.34	24.15	24.15	24.15	24.15	24.10	24.14	0.02	24.05	24.05	24.10	24.10	24.10	24.08	0.03	0.332
135	1.34	24.15	24.15	24.20	24.15	24.15	24.16	0.02	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.331
136	1.32	24.15	24.20	24.20	24.15	24.15	24.17	0.03	23.90	23.90	23.90	23.90	23.85	23.89	0.02	0.329
137	1.32	24.15	24.15	24.15	24.15	24.15	24.15	0.00	23.95	23.90	23.90	23.90	24.05	23.94	0.07	0.329
138	1.34	24.20	24.20	24.15	24.10	24.10	24.15	0.05	24.15	24.15	24.20	24.10	23.95	24.11	0.10	0.331
139	1.32	24.05	24.05	24.10	24.10	24.15	24.09	0.04	24.05	24.05	24.00	24.00	24.05	24.03	0.03	0.328
140	1.33	24.00	24.10	24.15	24.15	24.15	24.11	0.07	24.15	24.15	24.15	24.20	24.20	24.17	0.03	0.329
141	1.32	24.05	24.20	24.20	24.20	24.20	24.17	0.07	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.325
142	1.30	24.15	24.15	24.15	24.10	24.15	24.14	0.02	24.00	24.00	24.00	23.95	23.90	23.97	0.04	0.324
143	1.32	24.00	24.00	24.00	24.00	24.05	24.01	0.02	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.328
144	1.34	24.10	24.05	24.05	24.05	24.10	24.07	0.03	24.25	24.20	24.20	24.20	24.20	24.21	0.02	0.331
145	1.34	24.10	24.10	24.10	24.05	24.10	24.09	0.02	24.25	24.20	24.25	24.20	24.20	24.22	0.03	0.331
146	1.30	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.00	24.00	24.05	24.00	24.00	24.01	0.02	0.325
147	1.30	24.00	24.00	24.05	24.05	24.05	24.03	0.03	24.05	24.05	24.10	24.10	24.00	24.06	0.04	0.324
148	1.34	24.20	24.20	24.20	24.15	24.15	24.18	0.03	24.20	24.20	24.25	24.25	24.25	24.23	0.03	0.329
149	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.20	24.25	24.25	24.20	24.20	24.22	0.03	0.327
150	1.34	24.15	24.15	24.15	24.15	24.15	24.15	0.00	24.20	24.15	24.15	24.15	24.15	24.16	0.02	0.331

Table B-1 - First-Generation Base Panel Weights and Dimensions (7 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
151	1.32	24.05	24.00	24.00	23.90	23.80	23.95	0.10	24.20	24.15	24.15	24.10	24.05	24.13	0.06	0.329
152	1.34	24.20	24.20	24.15	24.15	24.10	24.16	0.04	24.20	24.20	24.20	24.20	24.15	24.19	0.02	0.330
153	1.32	23.80	23.80	23.80	23.80	23.80	23.80	0.00	24.20	24.20	24.20	24.10	24.00	24.14	0.09	0.331
154	1.32	24.10	24.10	24.10	24.00	23.95	24.05	0.07	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.327
155	1.34	24.20	24.20	24.20	24.20	24.05	24.17	0.07	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
156	1.34	24.15	24.15	24.10	24.10	24.00	24.10	0.06	24.15	24.15	24.10	24.10	24.10	24.12	0.03	0.332
157	1.36	24.15	24.20	24.20	24.15	24.15	24.17	0.03	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.335
158	1.33	24.00	24.05	24.05	24.10	24.10	24.06	0.04	24.10	24.15	24.20	24.15	24.10	24.14	0.04	0.330
159	1.34	24.15	24.10	24.10	24.10	24.15	24.12	0.03	24.20	24.15	24.10	24.10	24.15	24.14	0.04	0.331
160	1.34	24.10	24.20	24.20	24.20	24.15	24.17	0.04	24.00	24.00	24.00	24.00	24.05	24.01	0.02	0.333
161	1.36	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.334
162	1.34	23.80	23.80	23.80	23.75	23.75	23.78	0.03	24.10	24.15	24.20	24.20	24.25	24.18	0.06	0.336
163	1.36	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.334
164	1.34	24.00	24.10	24.15	24.15	24.20	24.12	0.08	24.20	24.25	24.20	24.20	24.20	24.21	0.02	0.330
165	1.34	24.20	24.20	24.20	24.15	24.15	24.18	0.03	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
166	1.34	24.20	24.20	24.20	24.15	24.10	24.17	0.04	24.15	24.15	24.15	24.15	24.10	24.14	0.02	0.331
167	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.15	24.15	24.10	24.10	24.05	24.11	0.04	0.331
168	1.36	24.20	24.20	24.20	24.20	24.15	24.19	0.02	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.335
169	1.36	24.10	24.10	24.15	24.15	24.20	24.14	0.04	24.00	24.10	24.10	24.00	23.80	24.00	0.12	0.338
170	1.35	24.15	24.20	24.15	24.15	24.15	24.16	0.02	24.15	24.20	24.20	24.20	24.20	24.19	0.02	0.333
171	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.329
172	1.36	24.10	24.15	24.15	24.15	24.10	24.13	0.03	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.335
173	1.34	24.15	24.20	24.20	24.25	24.20	24.20	0.04	23.90	23.95	24.00	23.95	23.90	23.94	0.04	0.333
174	1.34	24.10	24.15	24.15	24.20	24.20	24.16	0.04	24.20	24.20	24.20	24.20	24.20	24.20	0.00	0.330
175	1.34	24.20	24.20	24.20	24.20	24.20	24.20	0.00	24.00	24.05	24.05	24.00	23.95	24.01	0.04	0.332

Table B-1 - First-Generation Base Panel Weights and Dimensions (8 of 8)

	0.01 lbs	0.05 in														lb/ft^2
Panel Number	Bare Panel Weight	L1	L2	L3	L4	L5	Avg	Std Dev	W1	W2	W3	W4	W5	Avg	Std Dev	Aerial Weight
176	1.32	24.00	24.00	24.00	24.00	24.00	24.00	0.00	24.15	24.15	24.15	24.15	24.20	24.16	0.02	0.328
177	1.32	24.10	24.10	24.10	24.10	24.10	24.10	0.00	24.00	24.05	24.10	24.10	24.05	24.06	0.04	0.328
178	1.31	23.95	23.95	23.95	23.95	24.00	23.96	0.02	24.00	24.05	24.10	24.05	24.00	24.04	0.04	0.328
179	1.32	23.90	23.90	23.90	23.95	23.95	23.92	0.03	24.10	24.10	24.10	24.15	24.10	24.11	0.02	0.330
180	1.32	24.10	24.10	24.05	24.05	24.00	24.06	0.04	23.90	23.90	23.95	23.95	23.90	23.92	0.03	0.330
181	1.34	24.10	24.10	24.10	24.15	24.15	24.12	0.03	24.00	24.05	24.05	24.05	24.05	24.04	0.02	0.333
182	1.32	23.95	24.00	24.00	24.00	24.00	23.99	0.02	24.10	24.10	24.10	24.10	24.10	24.10	0.00	0.329
183	1.30	24.05	24.05	24.05	24.00	24.00	24.03	0.03	24.00	24.00	24.05	24.05	24.05	24.03	0.03	0.324
184	1.30	23.90	23.95	23.95	24.00	23.95	23.95	0.04	23.95	23.95	24.00	24.05	24.05	24.00	0.05	0.326
185	1.30	24.00	24.00	24.00	24.05	24.10	24.03	0.04	24.00	24.00	24.00	24.00	24.00	24.00	0.00	0.325
186	1.32	24.05	24.00	24.00	24.00	24.00	24.01	0.02	24.05	24.05	24.00	24.05	24.05	24.04	0.02	0.329
187	1.30	23.90	23.90	23.90	23.85	23.85	23.88	0.03	23.90	23.90	23.95	24.00	24.00	23.95	0.05	0.327
188	1.31	23.90	23.90	23.95	23.95	23.90	23.92	0.03	24.05	24.05	24.10	24.05	24.00	24.05	0.04	0.328
189	1.30	23.90	23.90	23.90	23.95	23.95	23.92	0.03	24.05	24.05	24.05	24.05	24.05	24.05	0.00	0.325
190	1.31	24.05	24.05	24.10	24.00	24.05	24.05	0.04	24.00	23.95	23.95	23.95	23.95	23.96	0.02	0.327
191	1.32	24.05	24.05	24.05	24.05	24.00	24.04	0.02	24.00	24.10	24.10	24.10	24.10	24.08	0.04	0.328

Appendix C -
First-Generation Thermography Report

REPORT TITLE:	NDI of NASA STAR-C^2 Test Article CFRP Panels		
REPORT #:	12-359-006 Rev. B	DATE:	6/7/12
TO:	Vicki Johnson	FROM:	Scott Brown
cc:	R. Boone	M. Daehling	I. Nelson
Approved by:	Jay Amos		

Subject Information

P/N:	NASA STAR-C^2 Test Articles	S/N:	
Part description:	7 plies Uni 0/45/90 F990201 (~.043" CPT): Oven-cured	Model:	
Inspector	S. Brown, M. Daehling, J. Amos	Charge #:	46002542
Inspector Level	2, 3		
Material Type	NCT321-G150/NAS-S-12K-UNI		
Type of Inspection	UT TTU Gantry, Pulse Echo & Thermography (IRT)		

Thru-transmission ultrasonic (TTU) gantry scans at 5 MHz with 0.08" index were completed pre-test and before any surface treatments applied. Panel labels are located in the lower-right corner of the C-scans. Some of the panels appeared to have significant mold release which affected UT couplant wetting. Wetting agent was applied to 3 different panels as a test with UT signal height observed before and after application with no dB change noticed. Water/Water reference amplitude was 32 dB @ 100% Full Screen Height (FSH). Scanning gain was set at 35 and 41 dB. Reference standard #3283000-1 was scanned with the panels for standardization.

Table 1 records the disposition in three categories (Passing Level 1, Passing Level 2 or Failing Level 2) of anomaly severity per CSTI009 - Level 2 acceptance size limit is 0.25 sq.in. UT attenuation values recorded in the table are not the worst areas on the panel, but an averaged value.

Post-impact grading levels were chosen as Grade 1: 0.063-0.25 sq.in., Grade 2: >0.25-0.56 sq.in. and Grade 3: >0.56-1.00 sq.in. of impact damage area.

Panels were selected from the lot for complementary thermography (2 ms flash duration) scans. Since IRT was done from the tool-side for pre-impact, these images were mirrored to align with the

gantry TTU C-scan orientation. For the sake of expediency, ~1.5” on the top and bottom edges of the panel were not covered in the IRT inspection.

Some panels were very clean, but quite a number contained high levels of scattered porosity. Potential causes were investigated in the TAM fabrication related to process conditions or material shelf life extension (prepreg apparently life extended at least once), but nothing conclusive could be found.

Photomicrography analysis (Figs. 268-270) revealed porosity levels up to 8.4% (local spots ~0.18” long) and averaging up to 3.9% (over a 1” area) in some of the most attenuative areas. The porosity tends to be linearly aligned as often found in UNI laminates. Therefore the same average porosity content typically has a higher detriment on both NDI & mechanical strength, as compared to uniformly distributed spherical porosity typically found in woven fabric composites.

TTU C-scans of the panels are oriented from the bag-side with the ID tag in the lower right corner (these Panel #’s re-numbered from the embedded ID tag #’s).

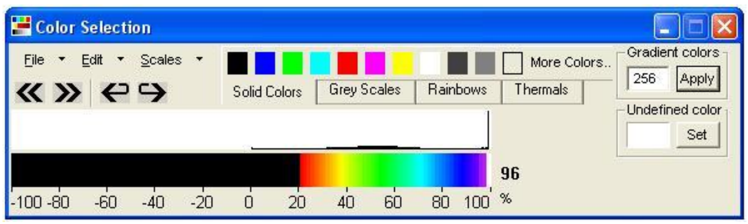


Figure 1. Ultrasonic C-Scan Plot Palette

In many of these panels the post-test detection of very small delaminations is not reliable (<~0.025 sq.in.) due to the generally higher levels of porosity content, in the lighting strike test panels in particular since higher quality panels were selected for impact.

Forty-four panels were used for lightning strike studies with damage sizing performed for the laminate substrate (back) side in thermography. Some of the lightning strike panels were inspected from the front side, but core or mesh damage was not typically sized due to the large degree of damage to the front surface. Without removal of any damaged protective clear film, lightning mesh and charred material followed by a tempera paint surface preparation, a reliable IRT inspection of front-side core damage could not be done.

Table 1. Baseline CSTI009 Disposition & Ultrasonic dB loss
(5.0 MHz Pulse Echo ½" dia. transducer)

Panel ID #	Disposition	PE-UT average max attenuation vs. ref. std. (dB)	Panel ID #	Disposition	PE-UT average max attenuation vs. ref. std. (dB)	Panel ID #	Disposition	PE-UT average max attenuation vs. ref. std. (dB)
1	Pass Level 2	5	70	Pass Level 1	3	139	Fail Level 2	6
2	Pass Level 1	5	71	Fail Level 2	8	140	Pass Level 2	6
3	Pass Level 1	2	72	Fail Level 2	2 with 4"x1" void	141	Fail Level 2	9
4	Pass Level 1	1	73	Fail Level 2	8	142	Fail Level 2	6
5	Fail Level 2	7	74	Pass Level 1	2	143	Pass Level 1	3
6	Pass Level 2	6	75	Fail Level 2	8	144	Pass Level 1	3
7	Pass Level 2	5	76	Pass Level 2	6	145	Pass Level 1	3
8	Pass Level 2	3	77	Fail Level 2	6	146	Pass Level 1	2
9	Pass Level 2	6	78	Pass Level 1	2	147	Pass Level 1	3
10	Pass Level 1	2	79	Pass Level 1	2	148	Pass Level 1	2
11	Pass Level 1	4	80	Pass Level 1	3	149	Pass Level 1	3
12	Pass Level 1	1	81	Fail Level 2	6	150	Fail Level 2	5
13	Pass Level 1	3	82	Pass Level 1	3	AS151	Pass Level 1	4
14	Pass Level 1	1	83	Fail Level 2	4	152	Pass Level 1	3
15	Pass Level 1	2	84	Pass Level 1	2	AS153	Fail Level 2	5
16	Pass Level 1	1	85	Fail Level 2	9	154	Pass Level 1	3
17	Pass Level 1	0	86	Pass Level 1	2	155	Fail Level 2	6
18	Pass Level 1	1	87	Fail Level 2	7	156	Fail Level 2	8
19	Pass Level 1	2	AS88	Fail Level 2	0	157	Pass Level 1	4
AS20	Pass Level 1	0	89	Pass Level 1	2	158	Fail Level 2	8
21	Pass Level 1	1	90	Pass Level 1	5	159	Fail Level 2	9
22	Pass Level 1	1	91	Pass Level 1	3	160	Pass Level 1	3
23	Fail Level 2	10	92	Pass Level 1	4	161	Pass Level 1	2
24	Fail Level 2	7	93	Pass Level 1	2	AS162	Pass Level 1	1
25	Fail Level 2	8	94	Fail Level 2	8	163	Pass Level 1	2
26	Fail Level 2	8	95	Pass Level 1	4	164	Pass Level 2	5
27	Fail Level 2	8	96	Fail Level 2	8	165	Fail Level 2	6
28	Pass Level 1	1	97	Pass Level 1	5	166	Fail Level 2	6
AS29	Fail Level 2	6	98	Fail Level 2	8	167	Pass Level 1	3
30	Fail Level 2	7	99	Fail Level 2	9	168	Pass Level 1	2
31	Pass Level 1	3	100	Pass Level 1	3	AS169	Pass Level 2	6
32	Fail Level 2	9	101	Fail Level 2	7	170	Fail Level 2	11
33	Fail Level 2	5	AS102	Pass Level 1	2	171	Fail Level 2	14
34	Fail Level 2	10	103	Pass Level 1	3	172	Pass Level 1	2
35	Pass Level 1	4	104	Fail Level 2	9	AS173	Pass Level 1	1
36	Pass Level 1	3	105	Fail Level 2	9	174	Pass Level 1	2
37	Pass Level 1	1	106	Fail Level 2	9	175	Pass Level 1	5
38	Pass Level 1	2	107	Fail Level 2	9	176	Fail Level 2	6
39	Pass Level 1	2	AS108	Fail Level 2	7	177	Pass Level 1	3
40	Pass Level 1	1	109	Fail Level 2	7	178	Fail Level 2	6
41	Pass Level 1	2	110	Fail Level 2	7	179	Fail Level 2	3
42	Pass Level 1	1	111	Fail Level 2	9	180	Pass Level 1	3
43	Pass Level 1	2	112	Fail Level 2	7	181	Pass Level 2	2
44	Pass Level 2	6	AS113	Pass Level 1	1	182	Fail Level 2	6
AS45	Pass Level 1	0	114	Pass Level 1	5	183	Pass Level 2	6
46	Pass Level 2	7	115	Fail Level 2	6	185	Pass Level 2	2
47	Pass Level 1	1	116	Fail Level 2	6	186	Pass Level 1	2
48	Pass Level 1	3	117	Fail Level 2	7	187	Pass Level 2	2
49	Pass Level 1	1	118	Pass Level 1	5	188	Pass Level 1	3
50	Pass Level 2	4	119	Pass Level 1	4	189	Pass Level 1	3
AS51	Fail Level 2	7	120	Pass Level 1	5	190	Pass Level 1	1
52	Pass Level 1	1	121	Pass Level 1	4	191	Pass Level 2	2
53	Fail Level 2	8	122	Pass Level 1	5	192	Fail Level 2	6
54	Pass Level 1	1	123	Pass Level 1	4			
55	Fail Level 2	6	124	Fail Level 2	7			
56	Pass Level 1	2	125	Fail Level 2	8			
57	Fail Level 2	8	126	Fail Level 2	7			
58	Pass Level 1	2	127	Fail Level 2	8			
59	Pass Level 1	1	128	Fail Level 2	10			
60	Pass Level 1	1	129	Fail Level 2	10			
61	Fail Level 2	7	130	Fail Level 2	9			
62	Fail Level 2	6	131	Fail Level 2	8			
63	Fail Level 2	8	132	Fail Level 2	7			
64	Fail Level 2	9	133	Fail Level 2	6			
65	Fail Level 2	8	134	Pass Level 2	7			
66	Fail Level 2	9	135	Fail Level 2	6			
67	Fail Level 2	6	AS136	Pass Level 2	6			
68	Pass Level 1	3	AS137	Pass Level 2	6			
69	Fail Level 2	7	138	Pass Level 2	6			

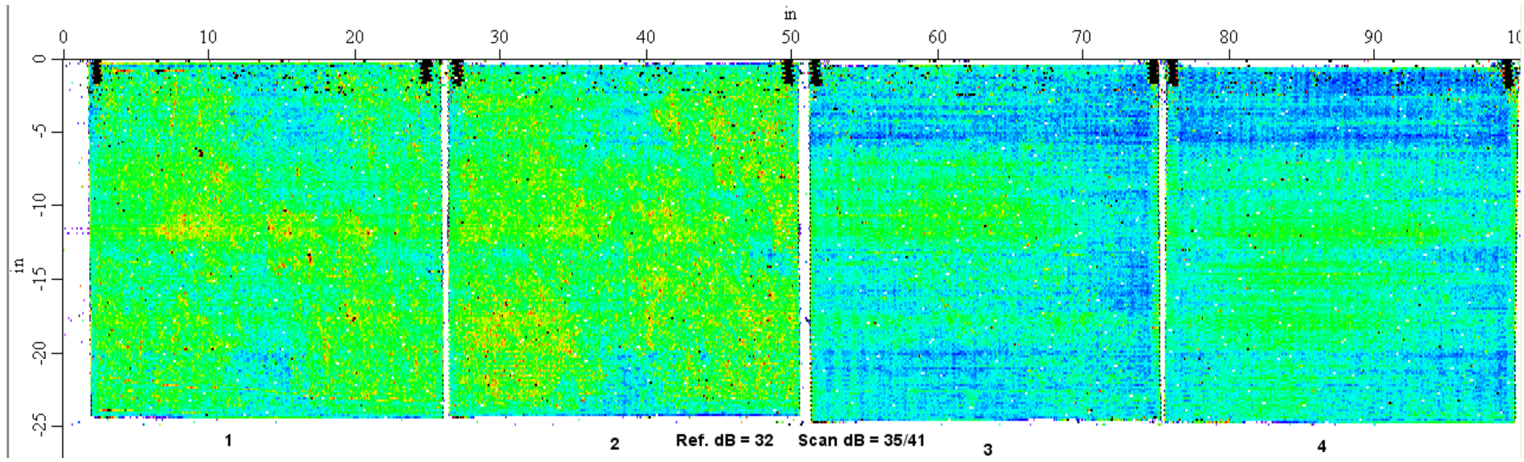


Figure 2. 5 MHz TTU Panel 1, 2, 3, 4

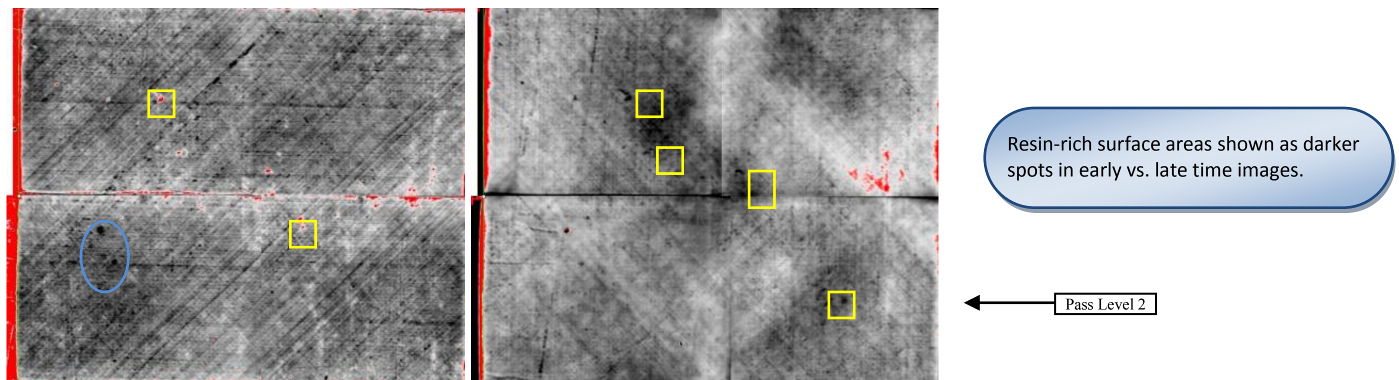


Figure 3. Thermography Panel 1 (1st Derv. - 0.42 & 0.94 sec)

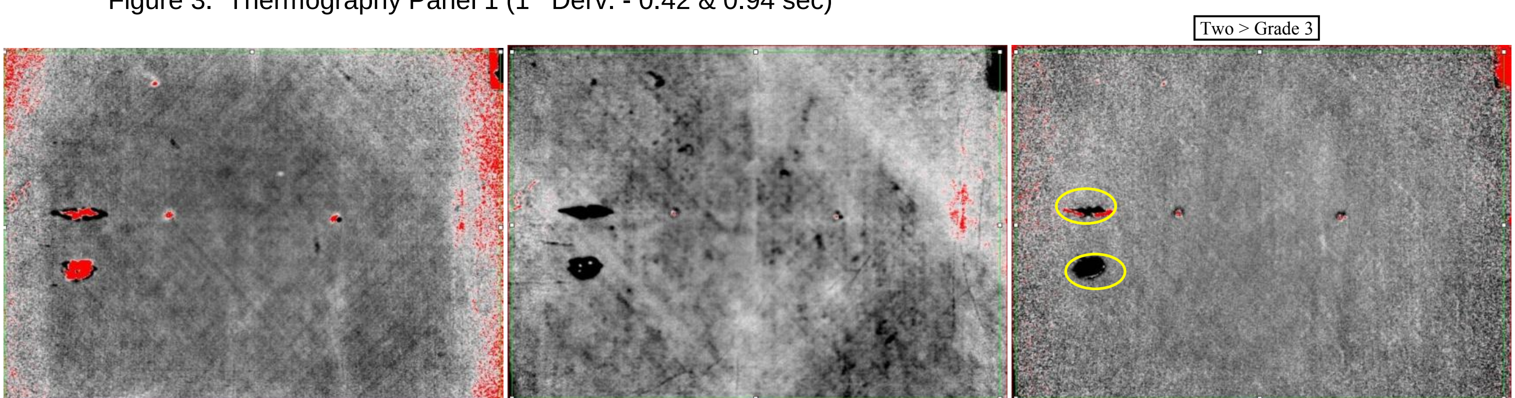


Figure 4. Post-Impact Thermography Panel 1 {IM-78} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

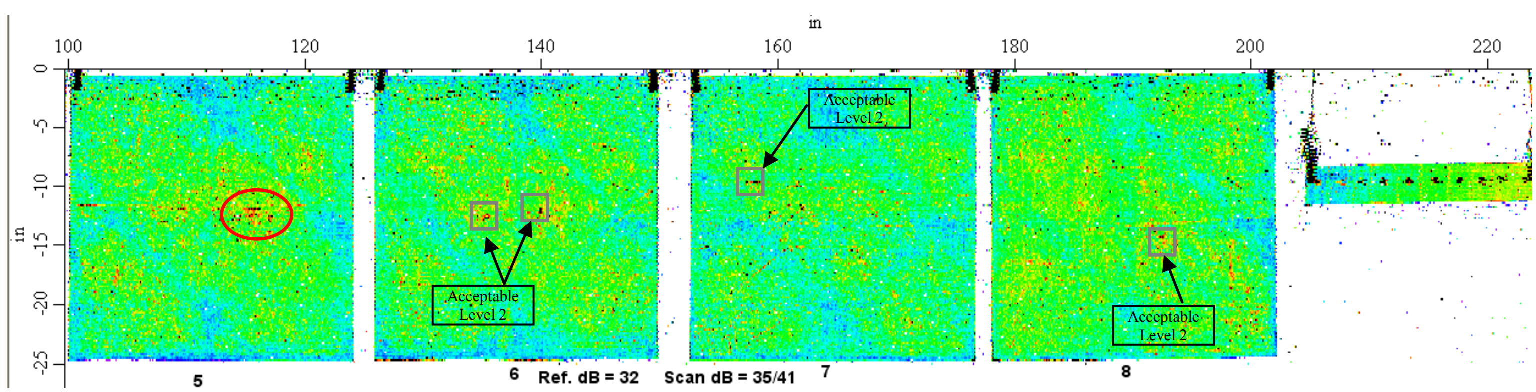


Figure 5. 5 MHz TTU Panel 5, 6, 7, 8

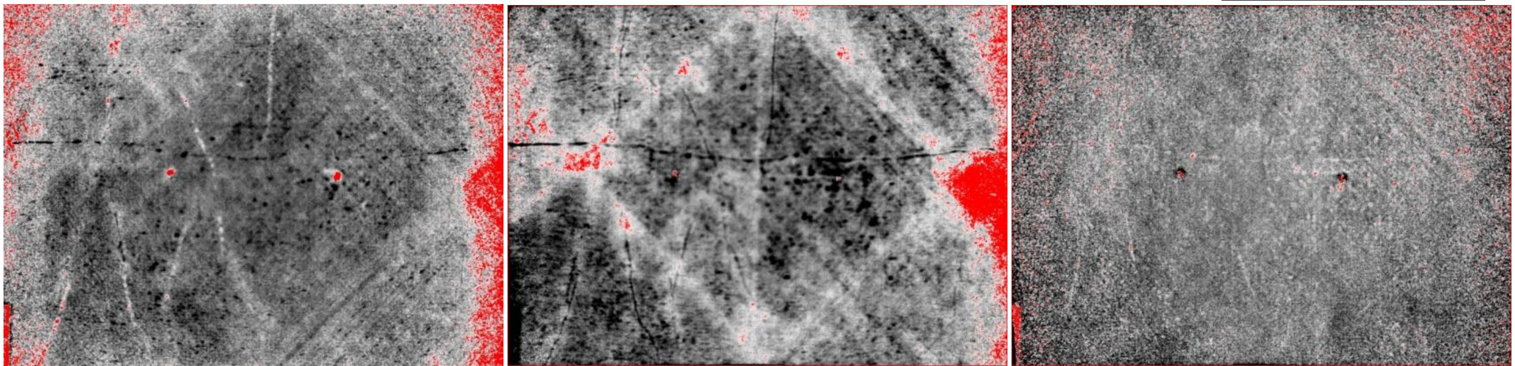


Figure 6. Post-Impact Thermography Panel 5 {IM-14} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

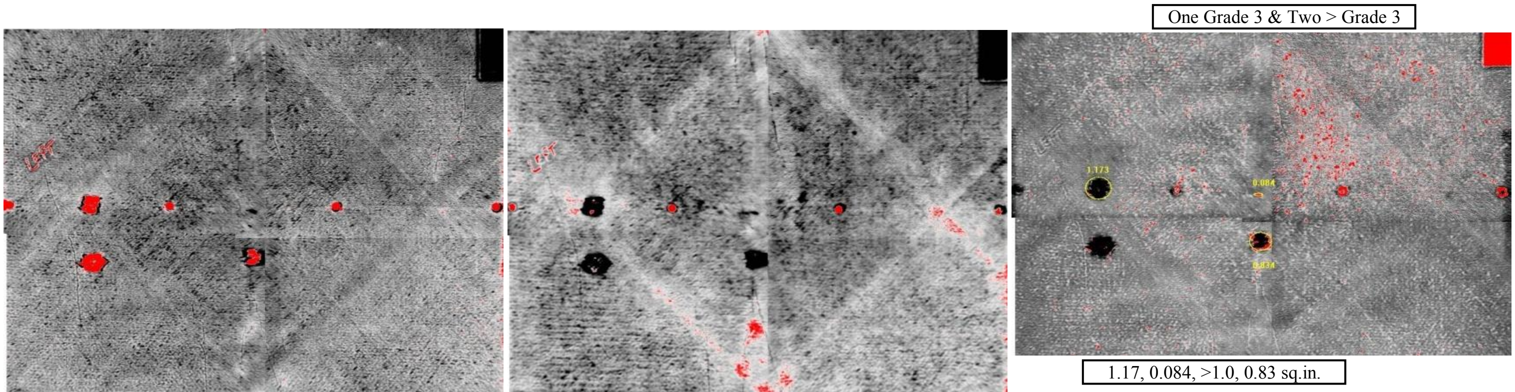


Figure 7. Post-Impact Thermography Panel 6 {IM-99} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

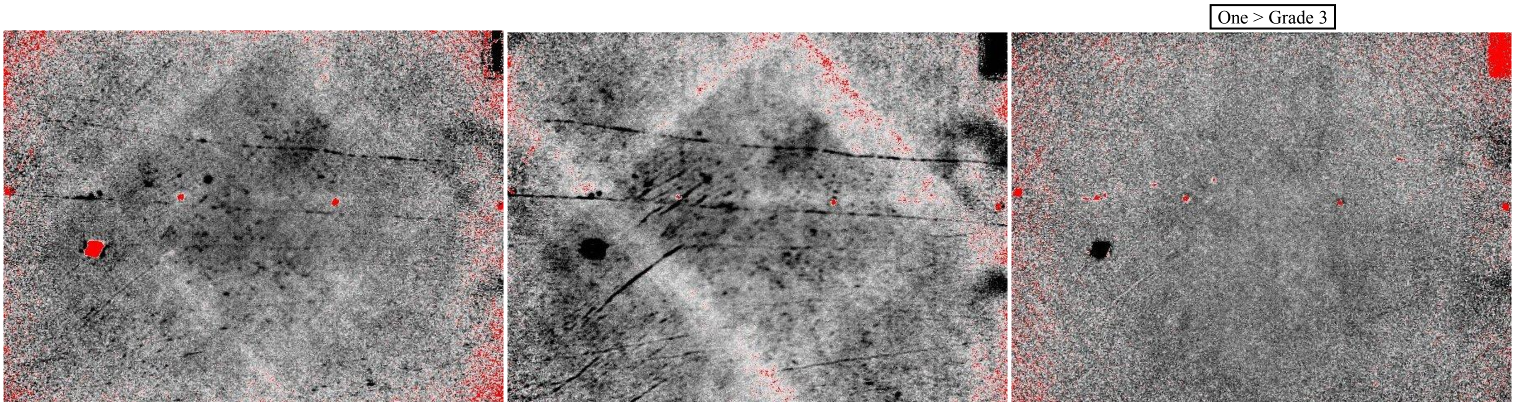


Figure 8. Post-Impact Thermography Panel 7 {IM-55} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

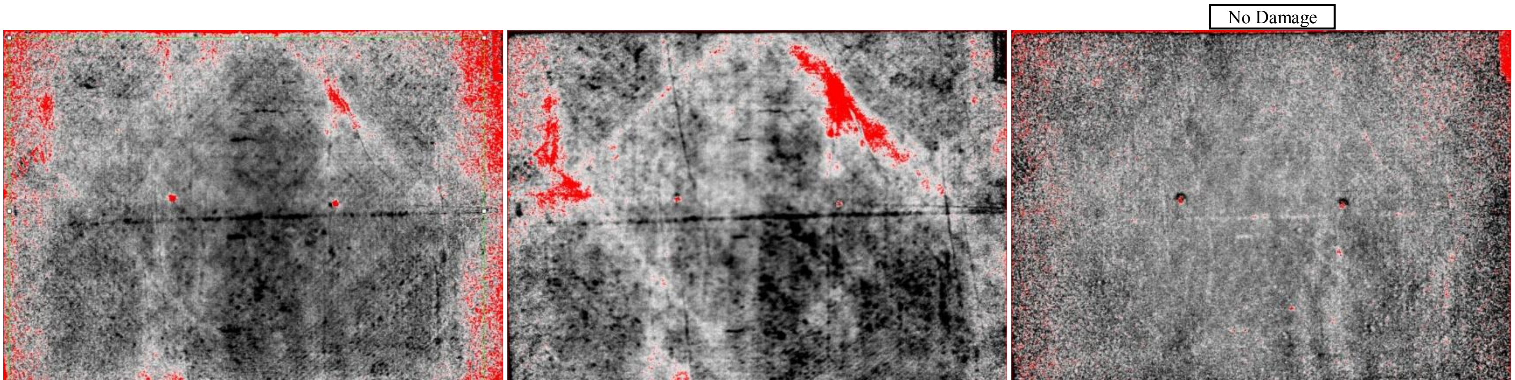


Figure 9. Post-Impact Thermography Panel 8 {IM-15} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

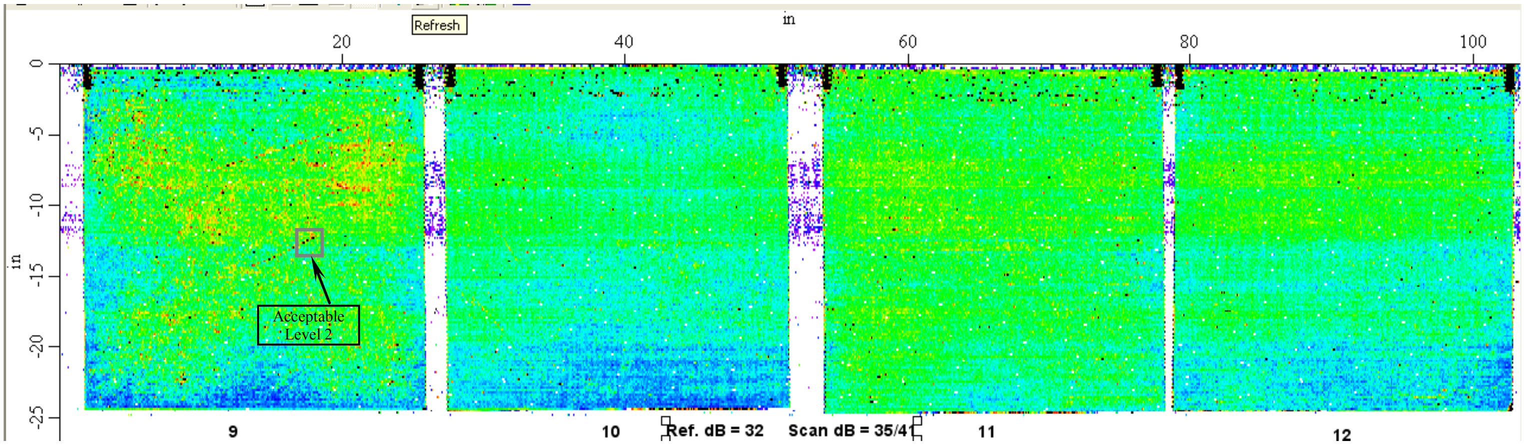


Figure 10. 5 MHz TTU Panel 9, 10, 11, 12

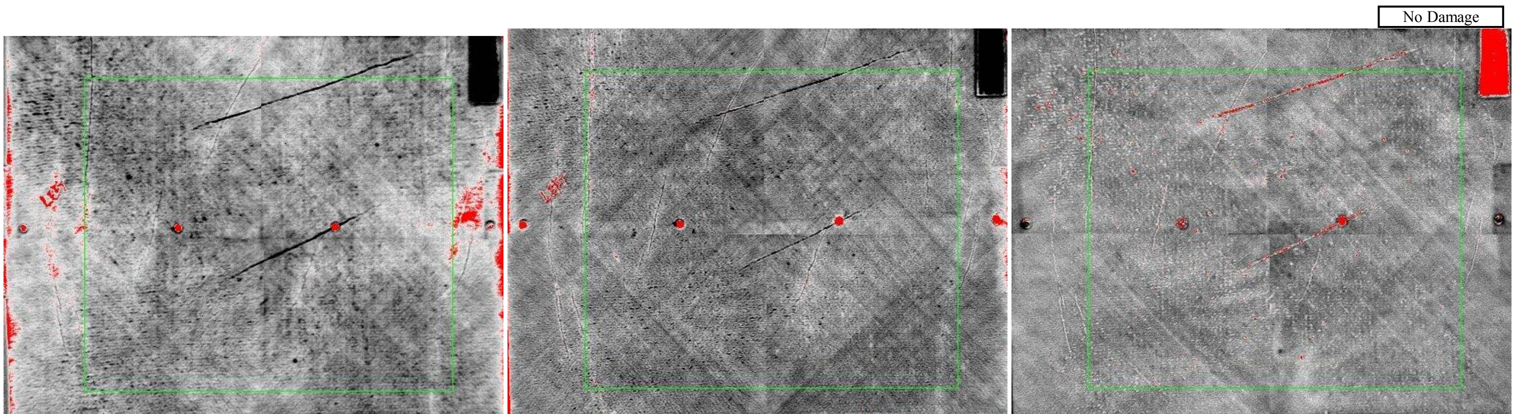


Figure 11. Post-Impact Thermography Panel 9 {IM-24} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

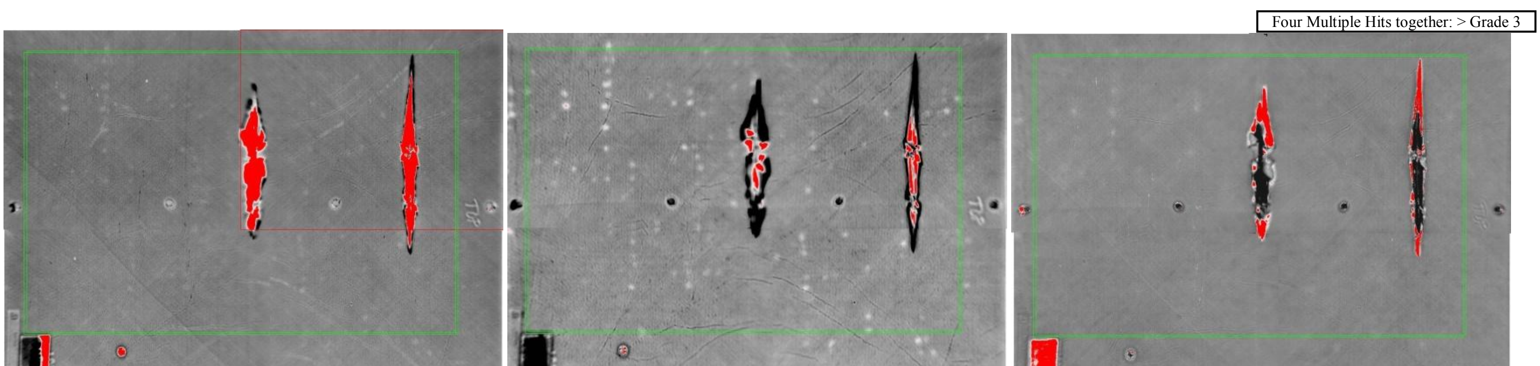


Figure 12. Post-Impact Thermography adhered Panel 12 {IM-88} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

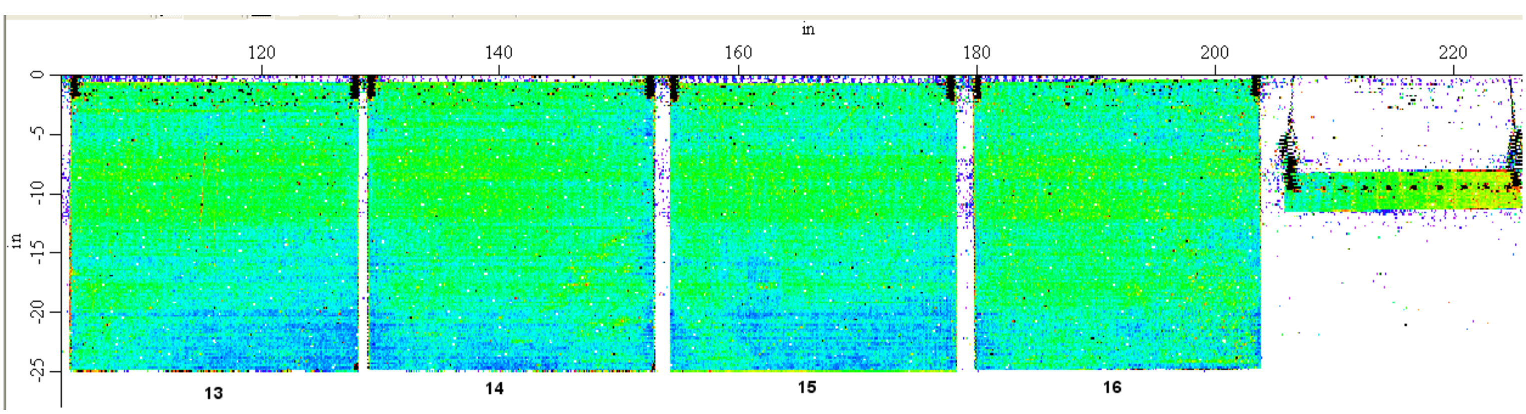


Figure 13. 5 MHz TTU Panel 13, 14, 15, 16

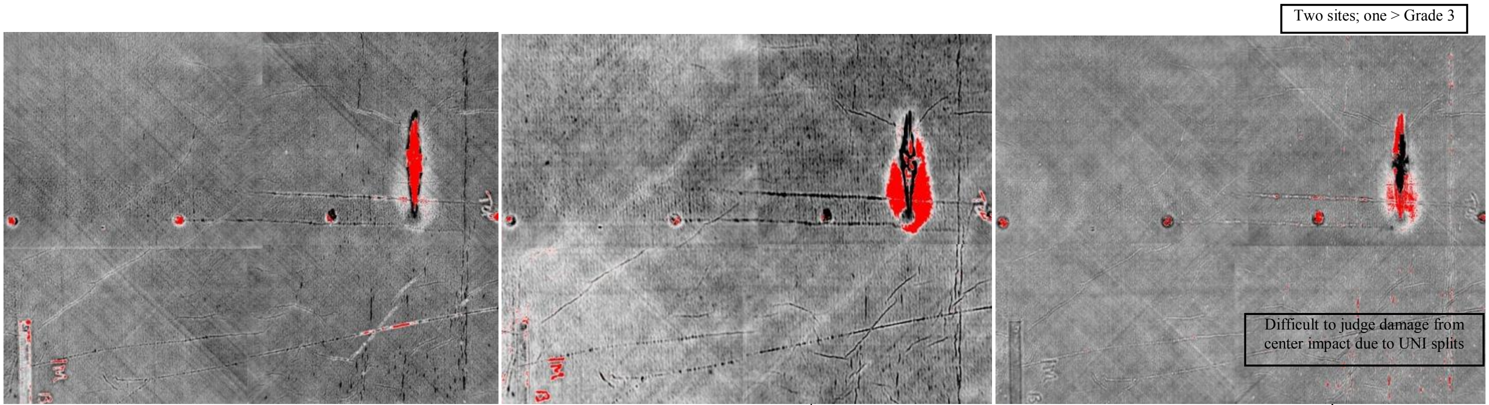


Figure 14. Post-Impact Thermography adhered Panel 13 {IM-65} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

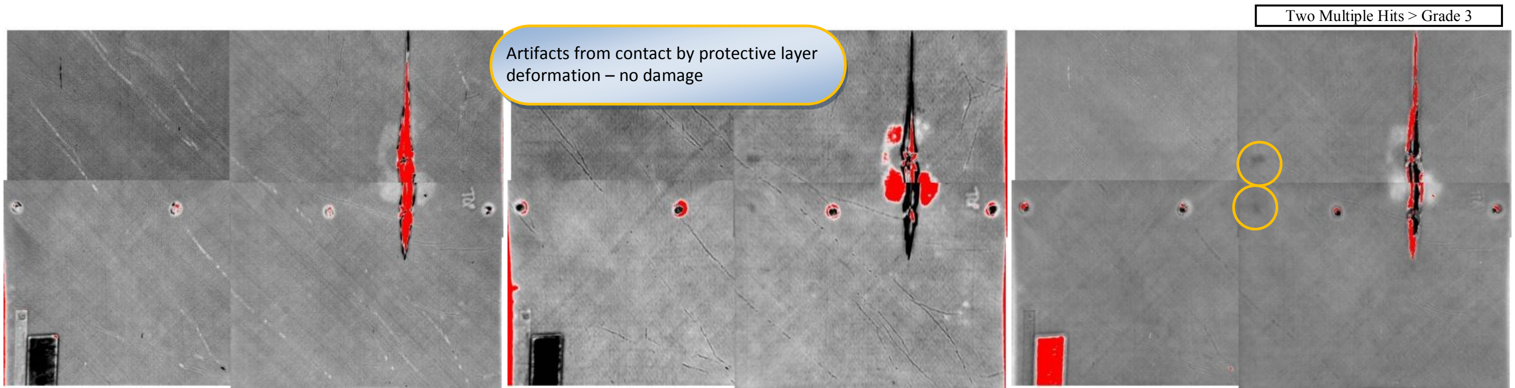


Figure 15. Post-Impact Thermography adhered Panel 14 {IM-44} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

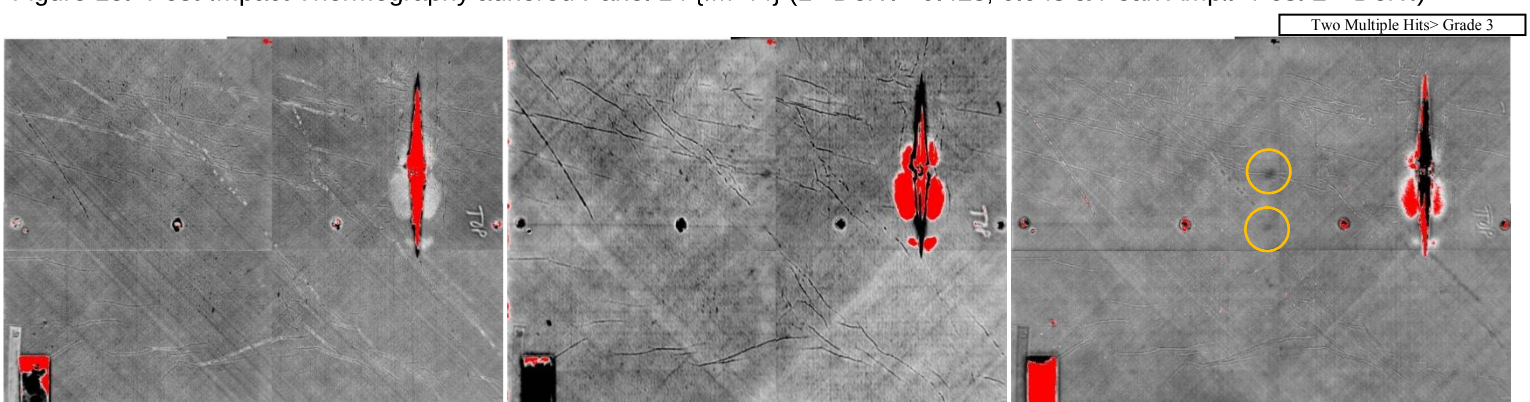


Figure 16. Post-Impact Thermography adhered Panel 15 {IM-58} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

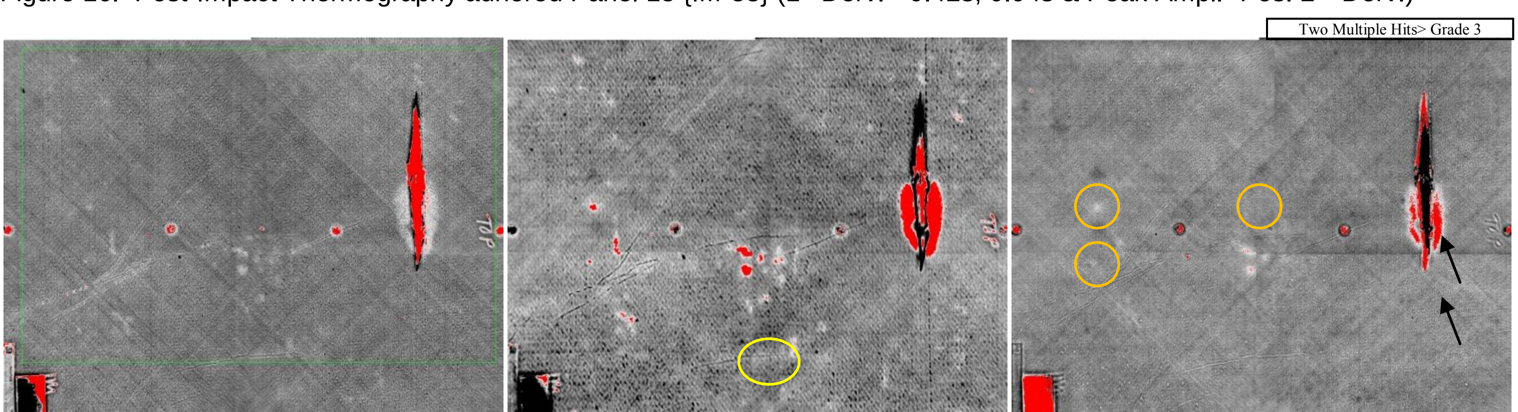


Figure 17. Post-Impact Thermography adhered Panel 16 {IM-67} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

Resin-rich spots

Artifacts from contact by protective layer deformation – no damage

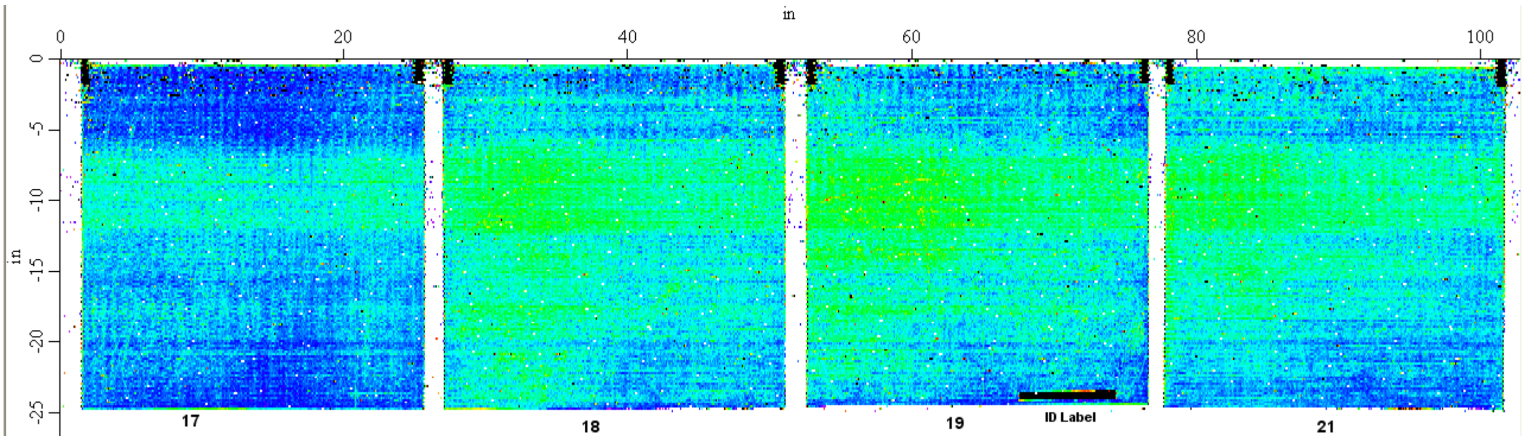


Figure 18. 5 MHz TTU Panel 17, 18, 19, 21

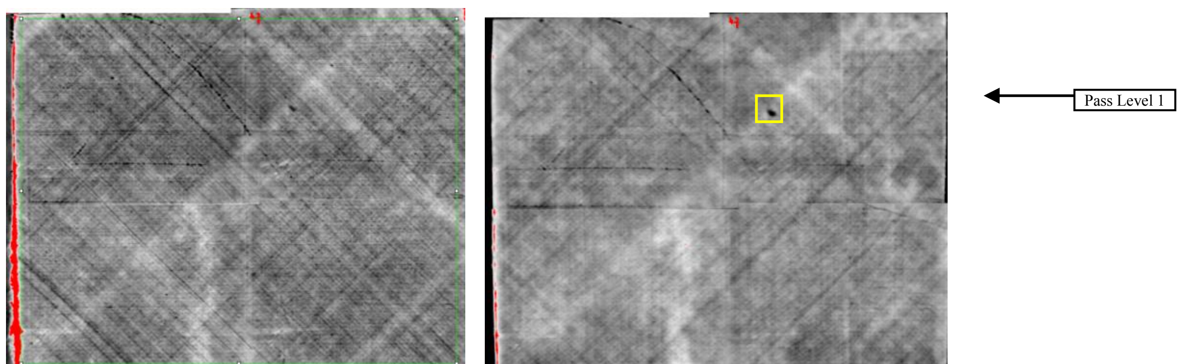


Figure 19. Thermography Panel 20 (1st Derv. - 0.42s & 0.94s)

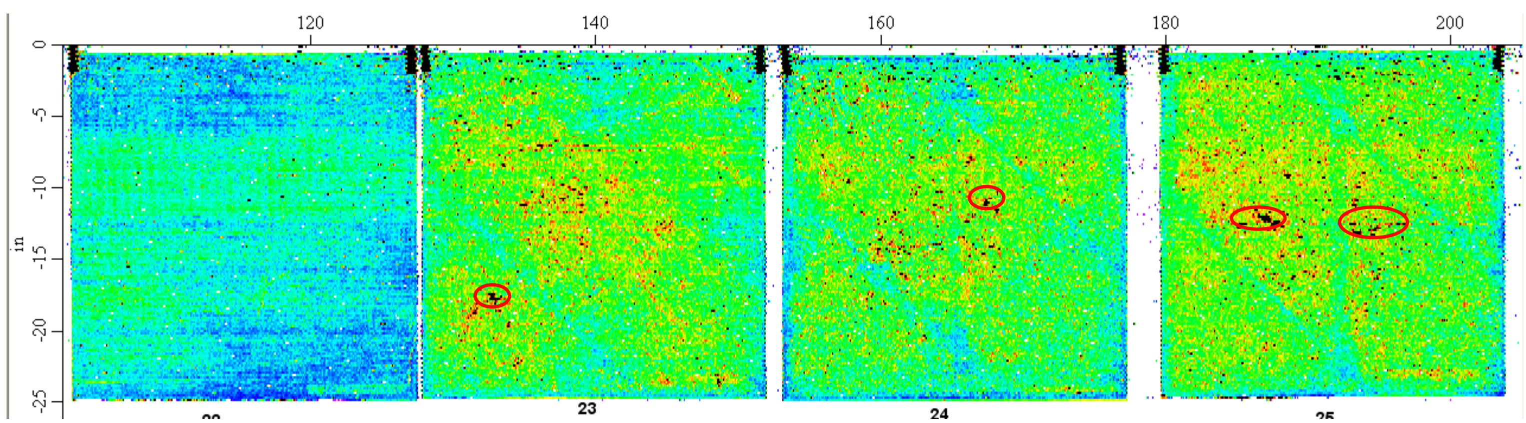


Figure 20. 5 MHz TTU Panel 22, 23, 24, 25

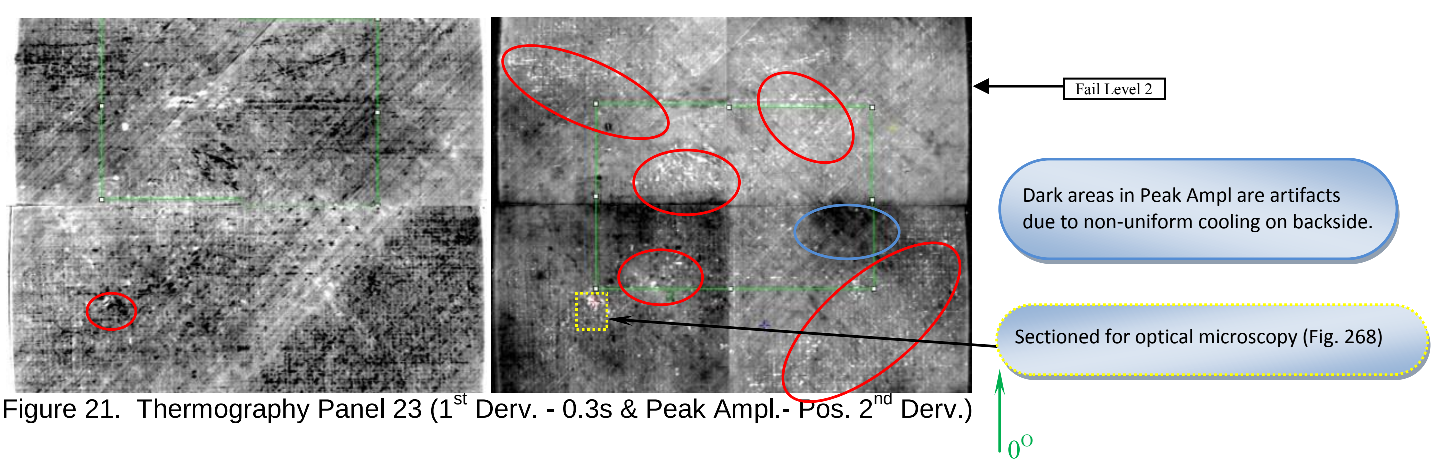


Figure 21. Thermography Panel 23 (1st Derv. - 0.3s & Peak Ampl.- Pos. 2nd Derv.)

One > Grade 3; 1.26 sq.in.

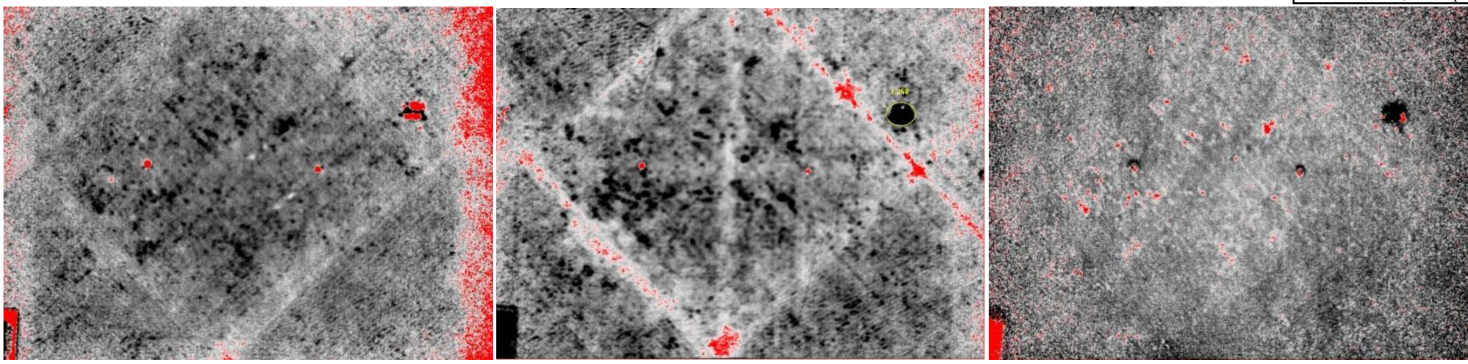


Figure 22. Post-Impact Thermography adhered Panel 24 {IM-4} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

One Grade 2 – 0.47 sq.in.
One > Grade 3

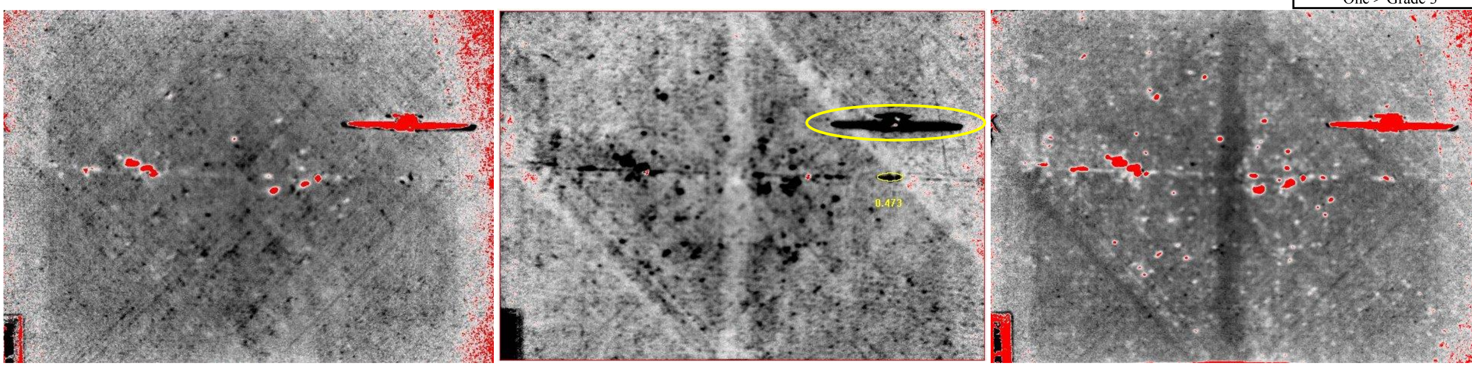


Figure 23. Post-Impact Thermography adhered Panel 25 {IM-79} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

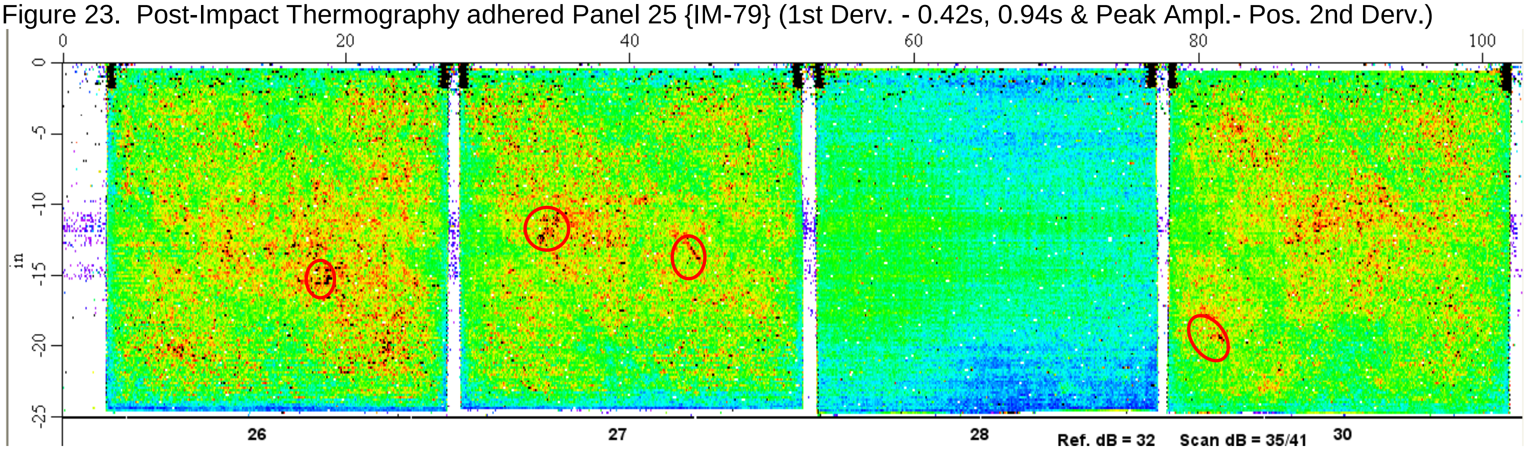


Figure 23. 5 MHz TTU Panel 26, 27, 28, 30

No Apparent Damage – porosity is high
in region of interest (Fails Level 2)

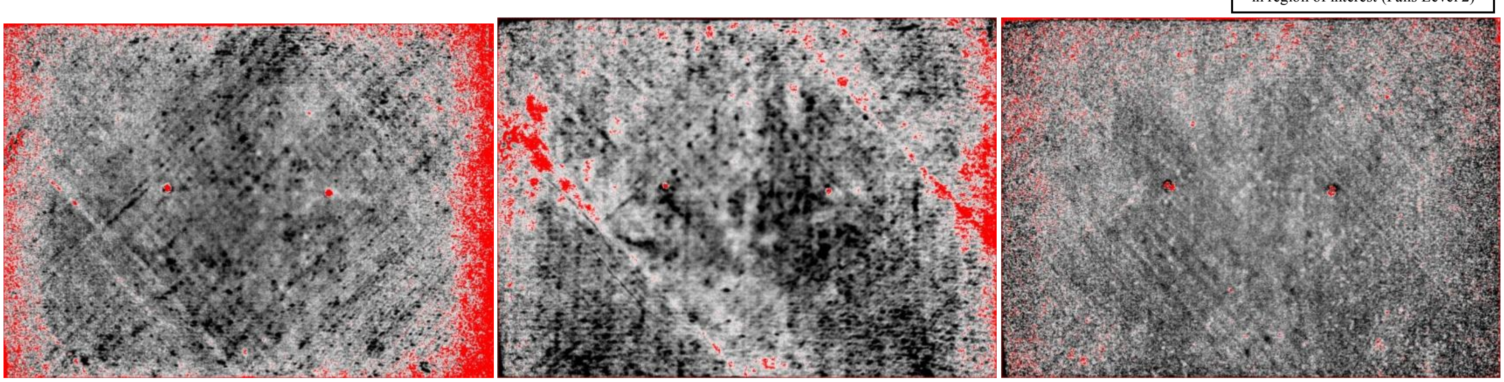


Figure 24. Post-Impact Thermography Panel 26 {IM-32} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

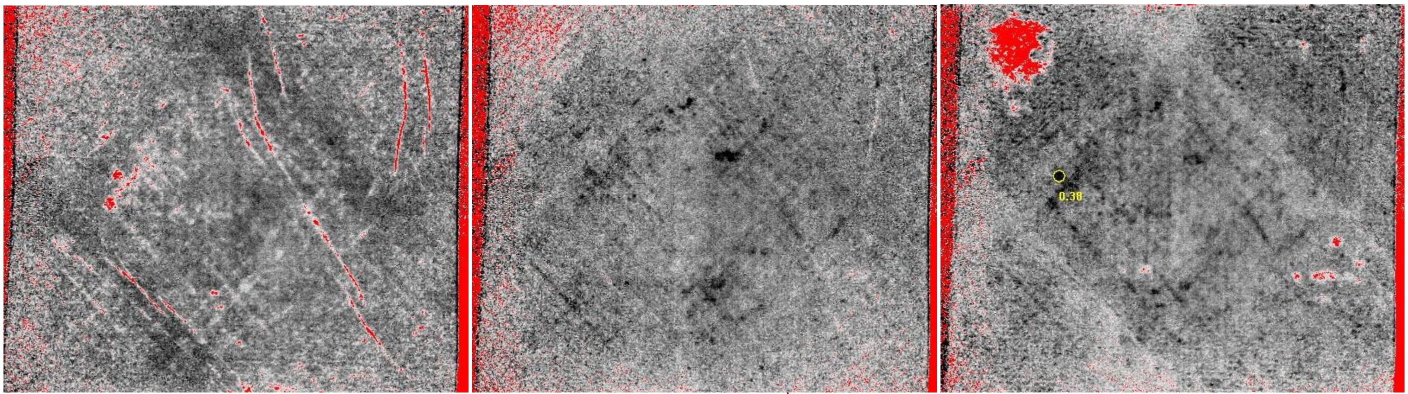


Figure 25. Post-Strike Thermography Back Panel 27 {LS-44} (1st Derv. – 0.08s, 0.42s, 0.94s)

Porosity from fabrication

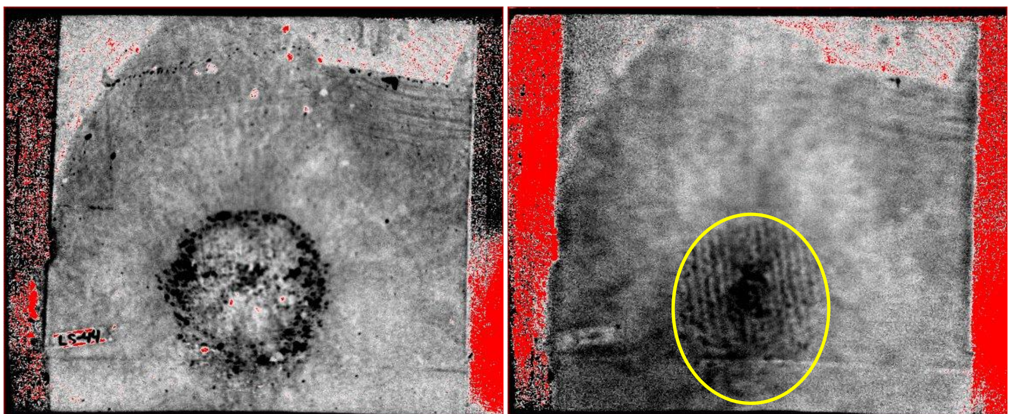
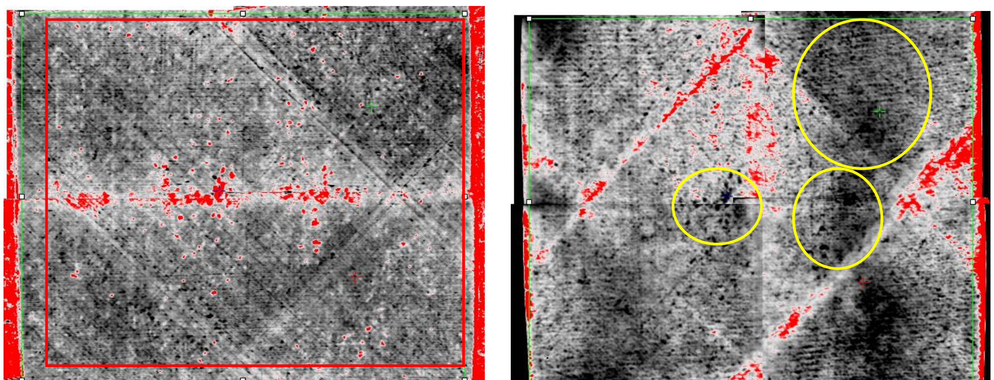


Figure 26. Post-Strike Thermography Front Panel 27 {LS-44} (1st Derv. – 0.4s & 8.66s)



Dark areas in late time are artifacts due to non-uniform cooling on backside.

Fail Level 2

Figure 27. Thermography Panel 29 (1st Derv. - 0.42s & 0.94s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

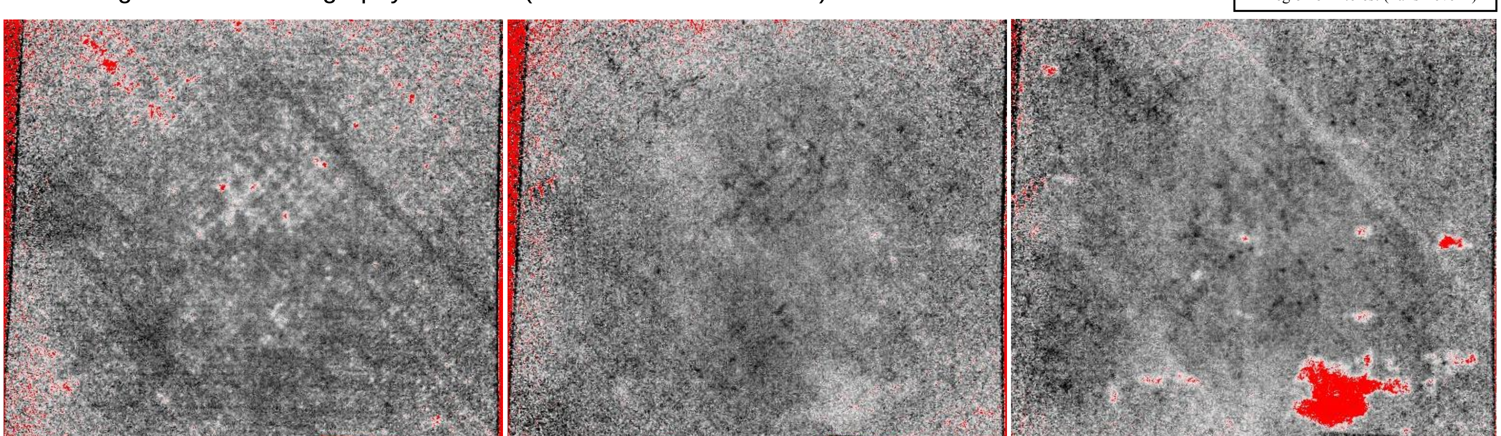


Figure 28. Post-Strike Thermography Back Panel 30 {LS-41} (1st Derv. – 0.08s, 0.42s, 0.94s)

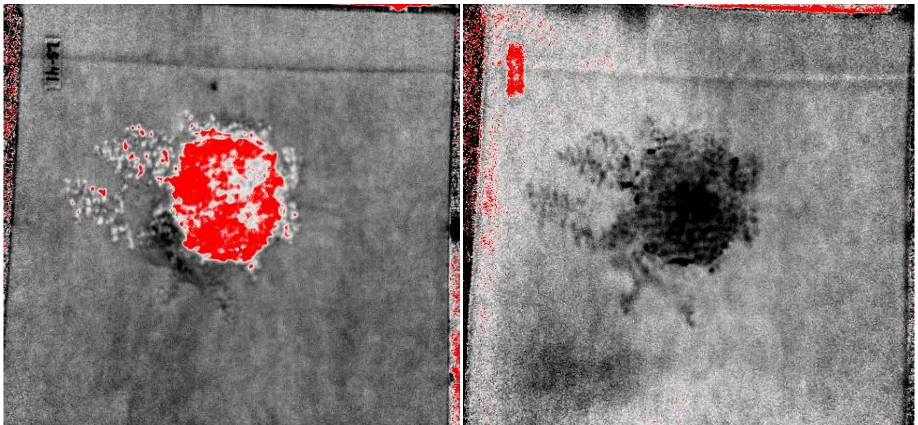


Figure 29. Post-Strike Thermography Front Panel 30 {LS-41} (1st Derv. – 0.4s & 8.66s)

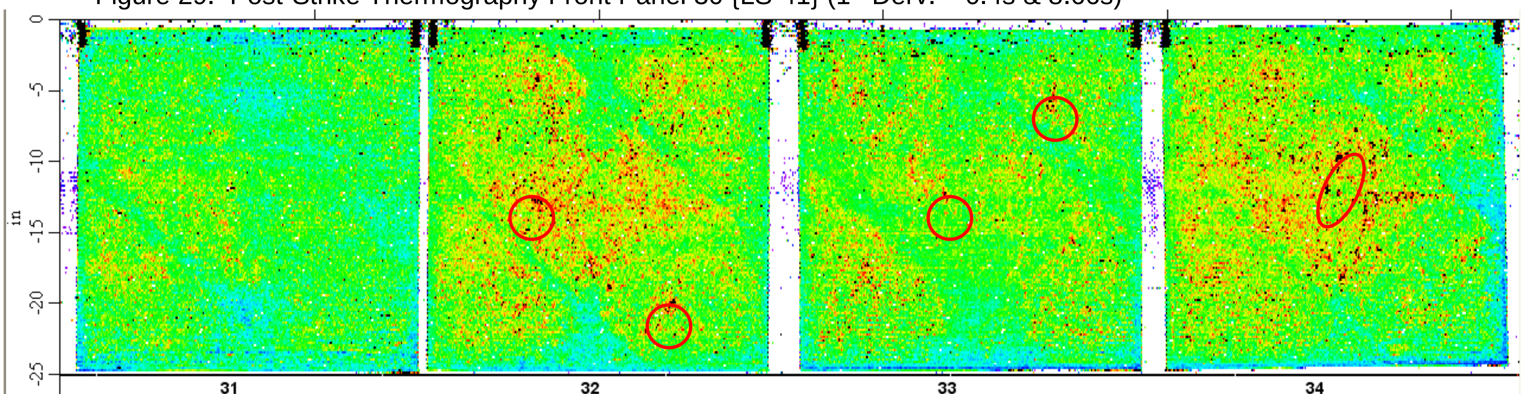


Figure 30. 5 MHz TTU Panel 31, 32, 33, 34

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

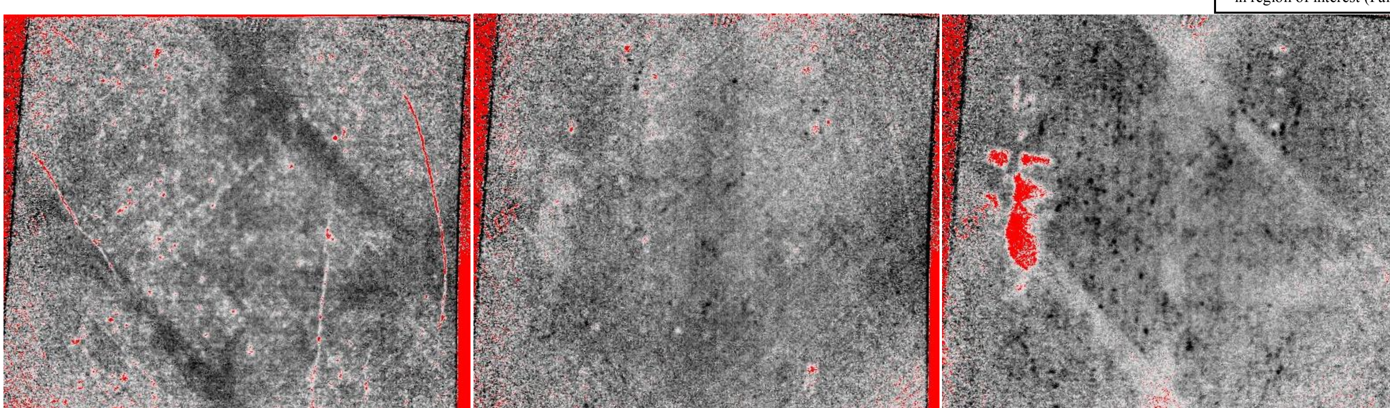


Figure 31. Post-Strike Thermography Back Panel 32 {LS-43} (1st Derv. – 0.08s, 0.42s, 0.94s)

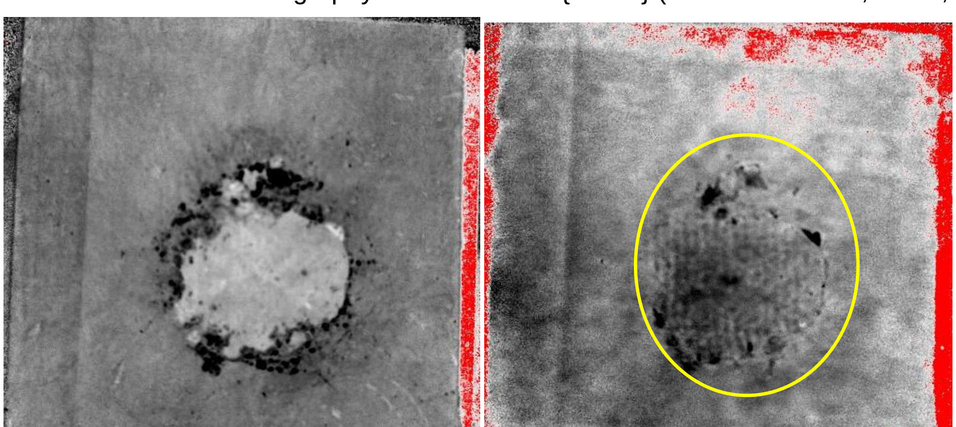


Figure 32. Post-Strike Thermography Front Panel 32 {LS-43} (1st Derv. – 0.4s & 8.66s)

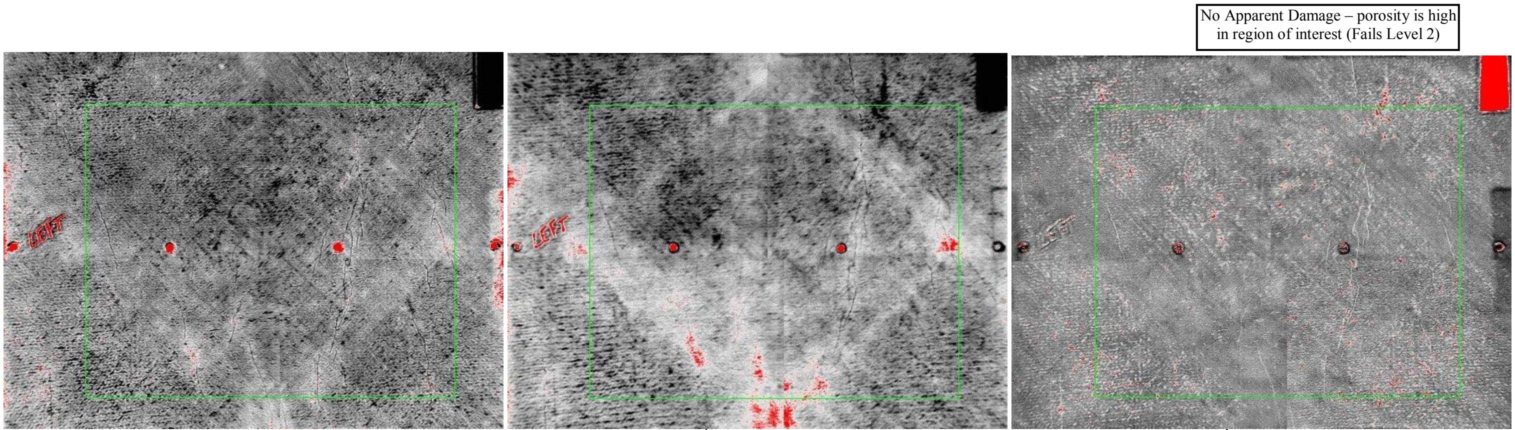


Figure 33. Post-Impact Thermography Panel 33 {IM-18} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

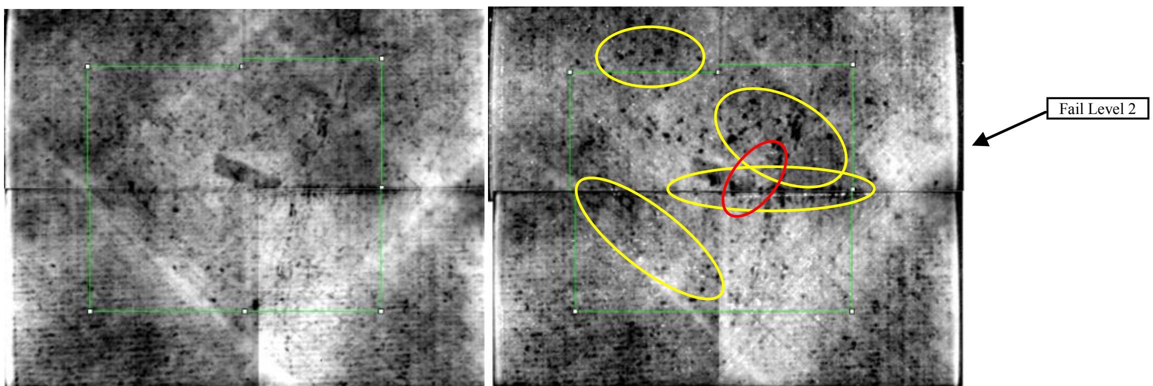


Figure 34. Thermography Panel 34 (1st Derv. - 0.3s & Peak Ampl.- Pos. 2nd Derv.)

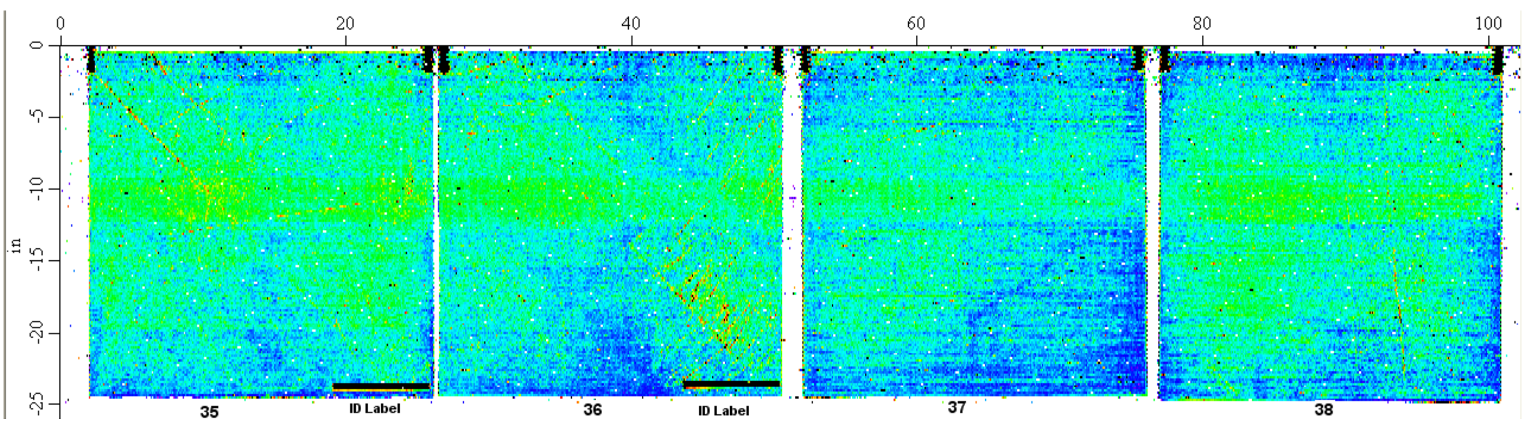


Figure 35. 5 MHz TTU Panel 35, 36, 37, 38

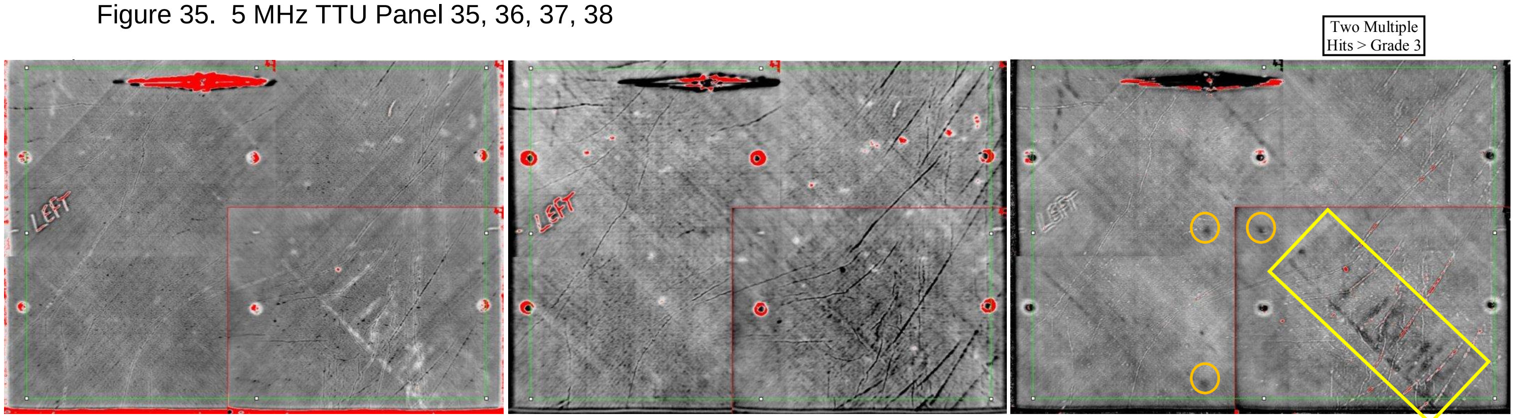


Figure 36. Post-Impact Thermography adhered Panel 36 {IM-45} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

Artifacts from contact by protective layer deformation

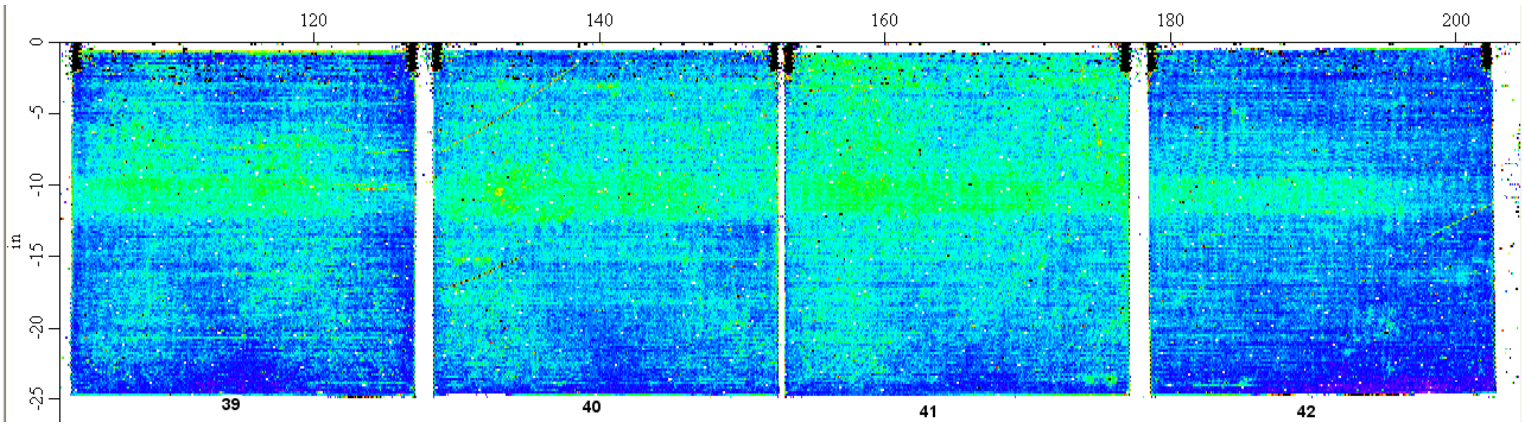


Figure 37. 5 MHz TTU Panel 39, 40, 41, 42

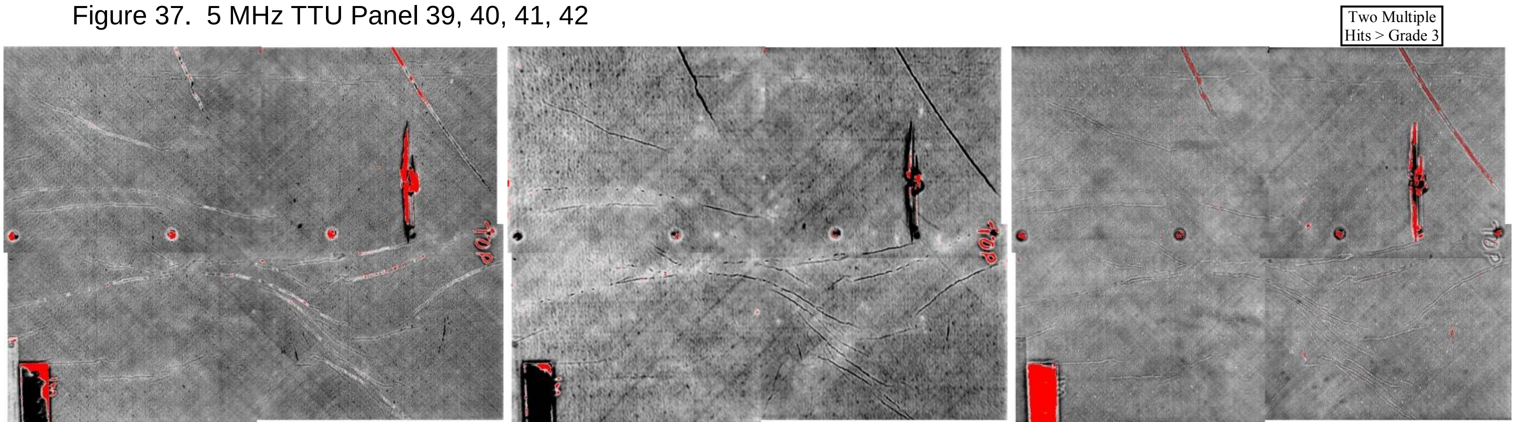


Figure 38. Post-Impact Thermography adhered Panel 40 {IM-64} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

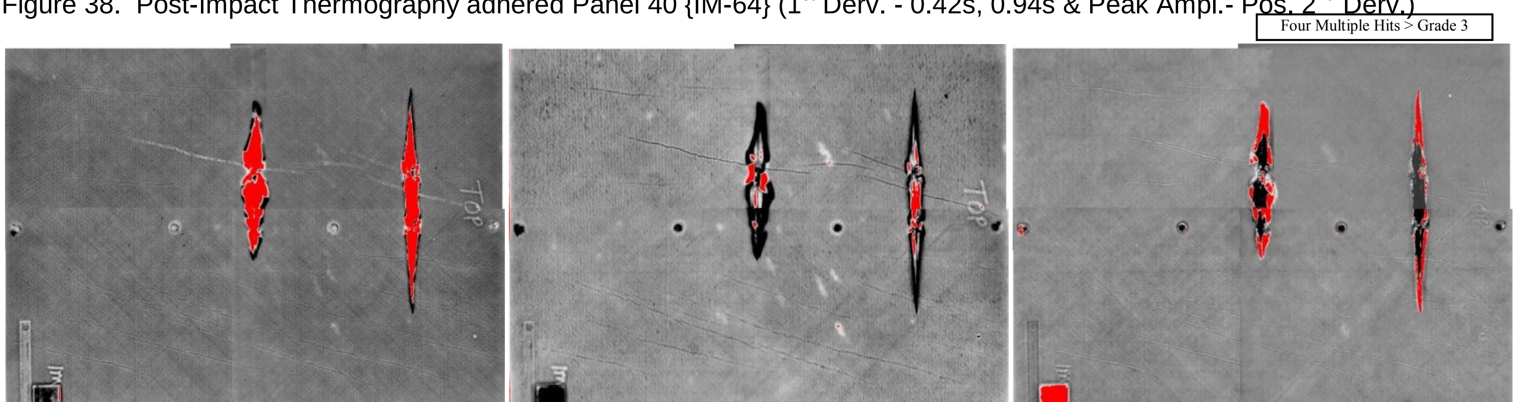


Figure 39. Post-Impact Thermography adhered Panel 41 {IM-94} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

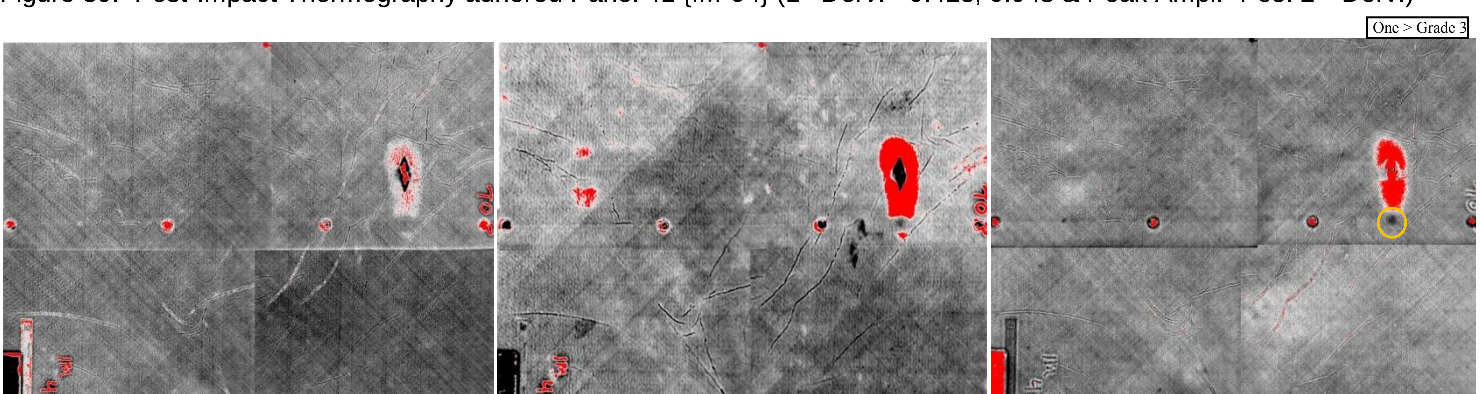


Figure 40. Post-Impact Thermography adhered Panel 42 {IM-71} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

Artifacts from contact by protective layer deformation

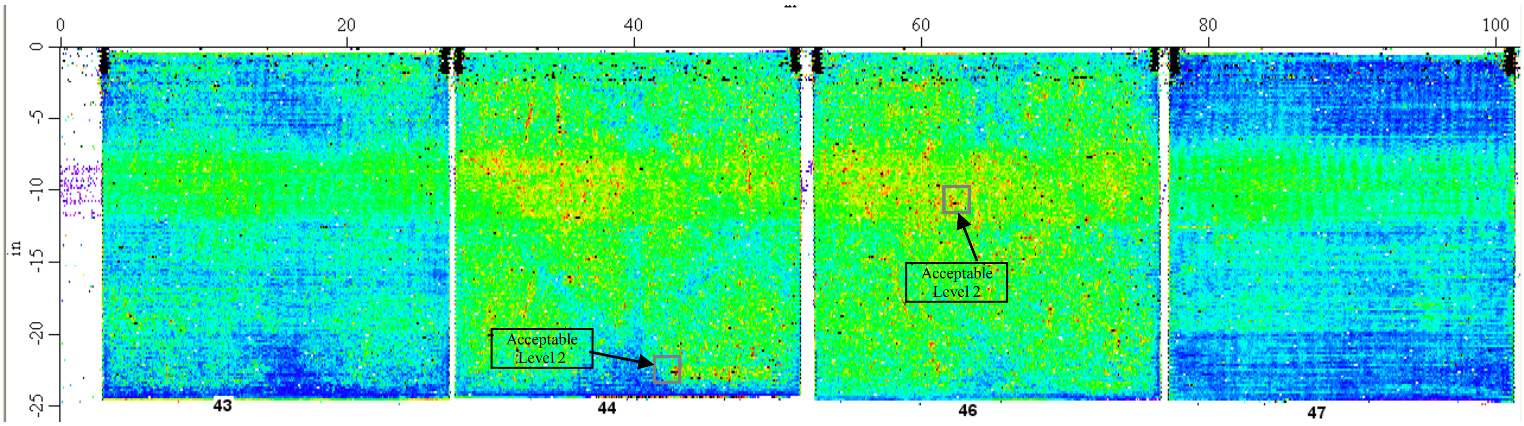


Figure 41. 5 MHz TTU Panel 43, 44, 46, 47

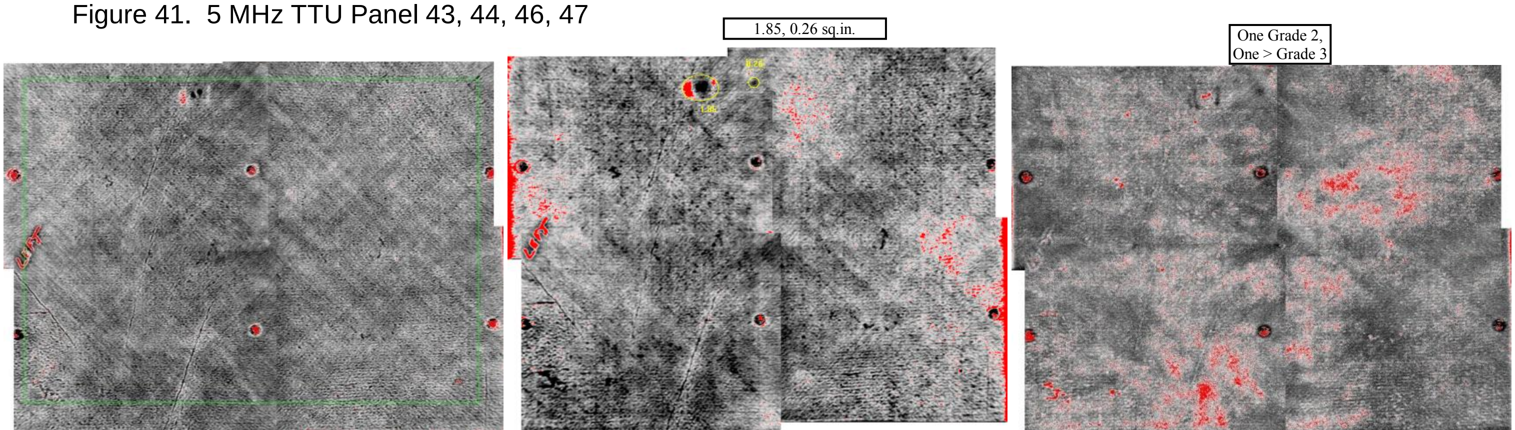


Figure 42. Post-Impact Thermography adhered Panel 43 {IM-68} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

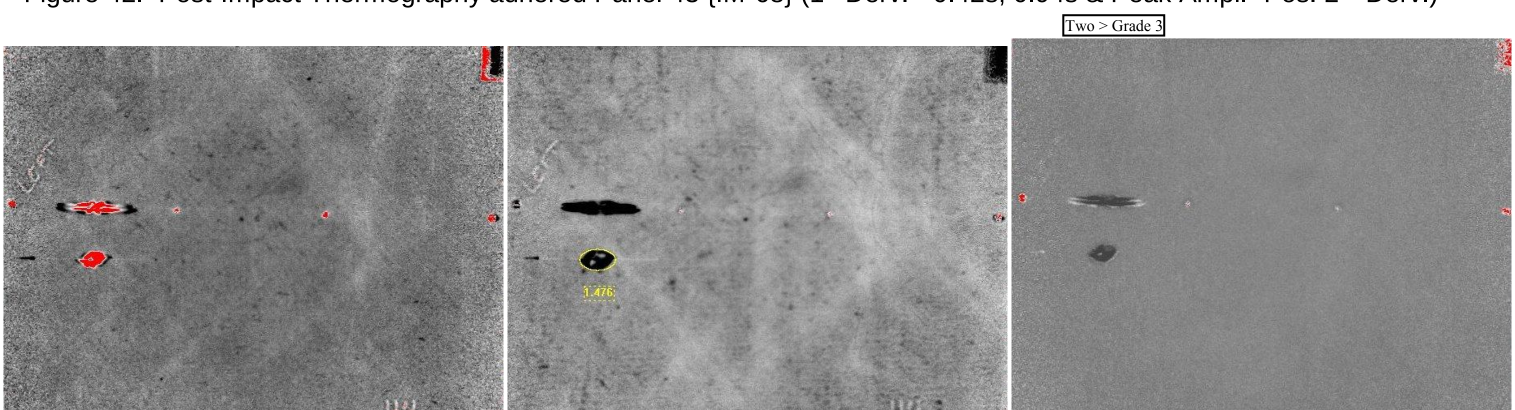


Figure 43. Post-Impact Thermography Panel 44 {IM-72} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

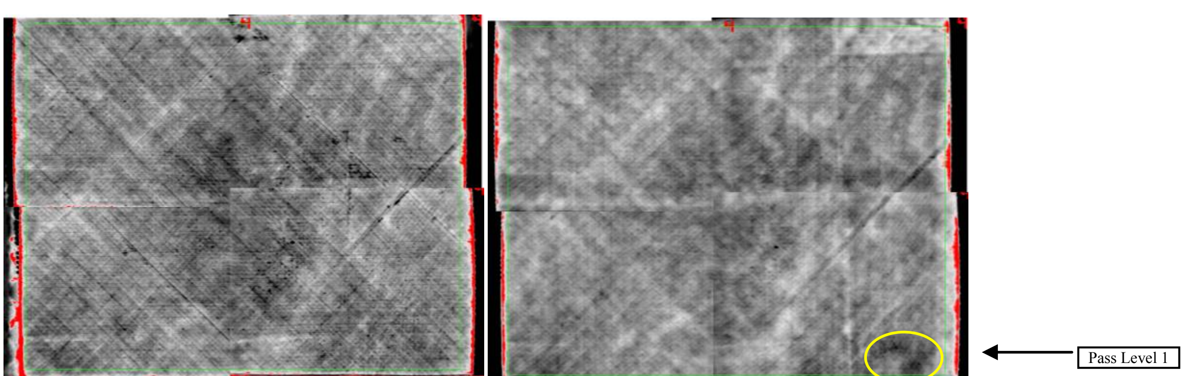


Figure 44. Thermography Panel AS45 (1st Derv. - 0.42 & 0.94 sec)

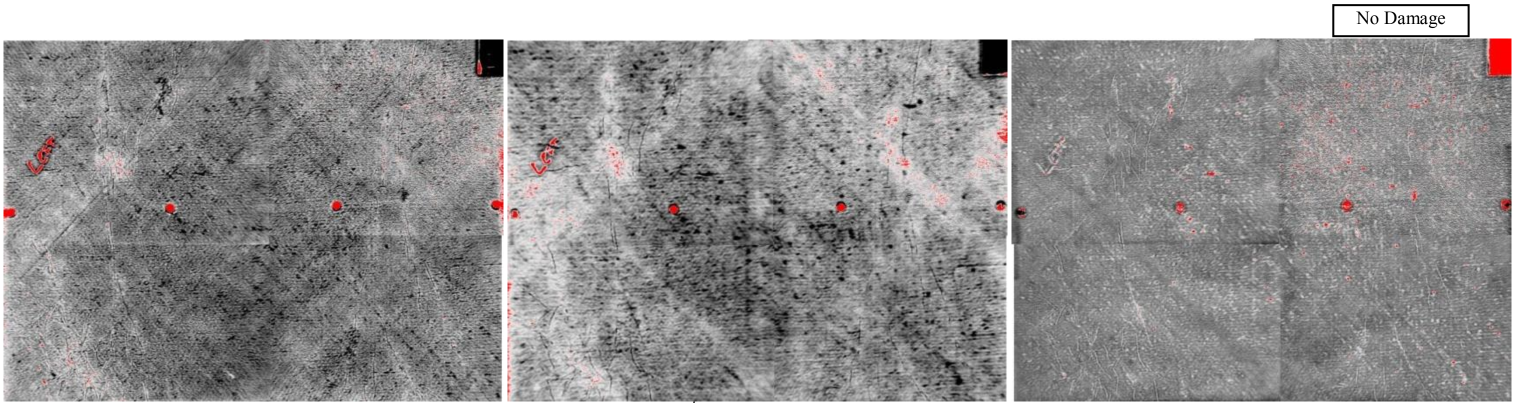


Figure 45. Post-Impact Thermography Panel 46 {IM-27} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.)

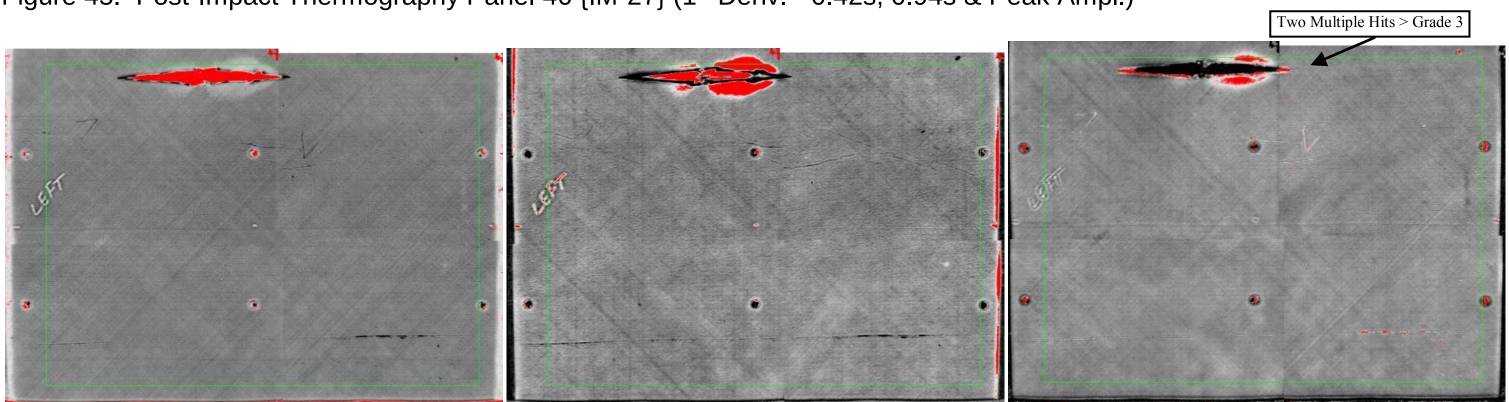


Figure 46. Post-Impact Thermography adhered Panel 47 {IM-62} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

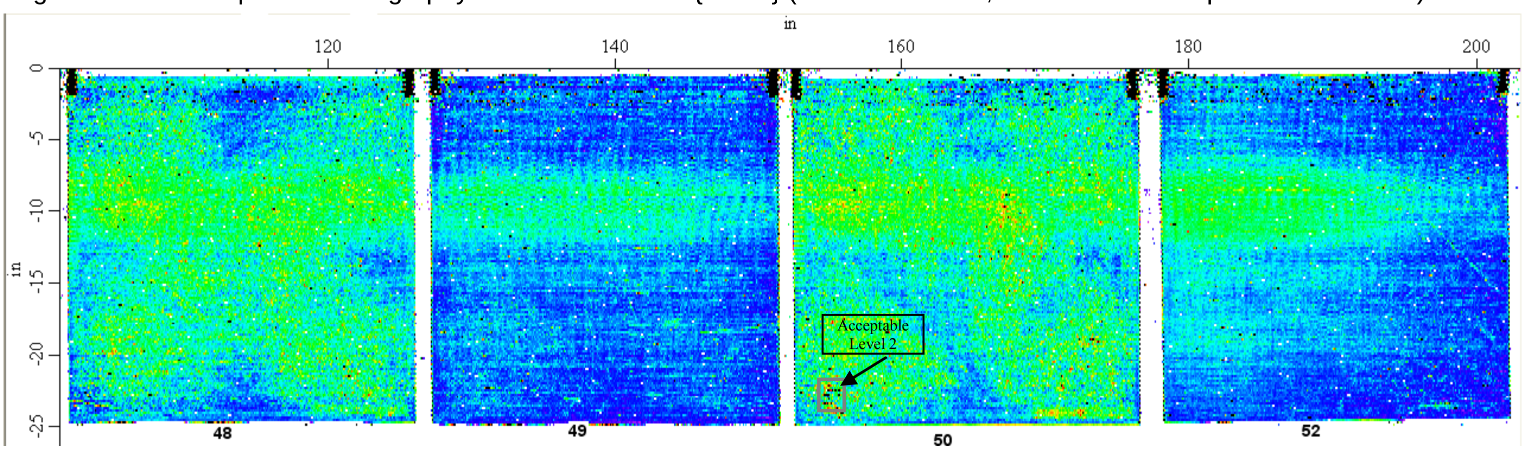


Figure 47. 5 MHz TTU Panel 48, 49, 50, 52

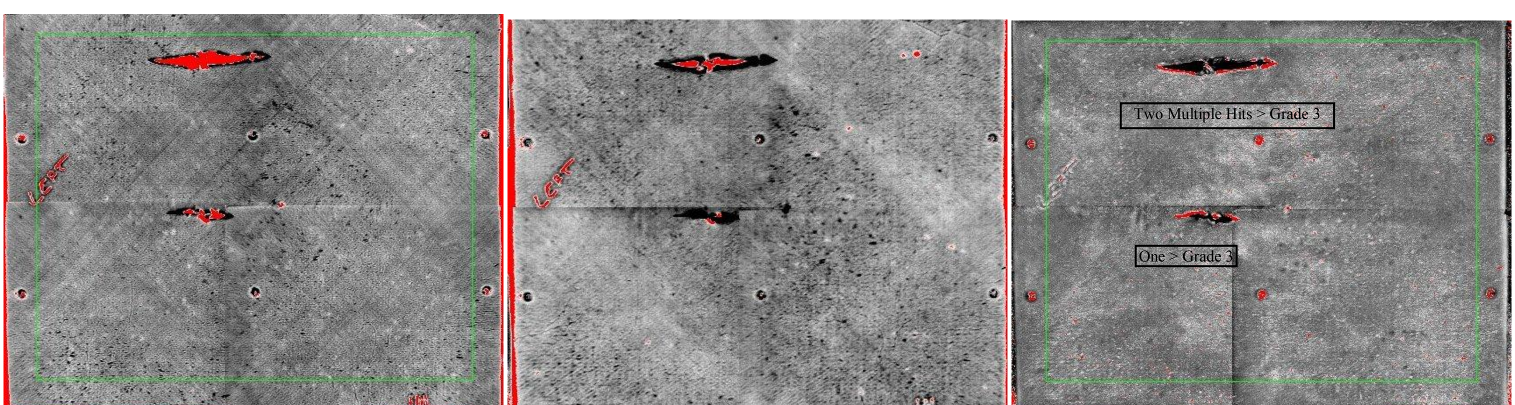


Figure 48. Post-Impact Thermography Panel 48 {IM-89} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

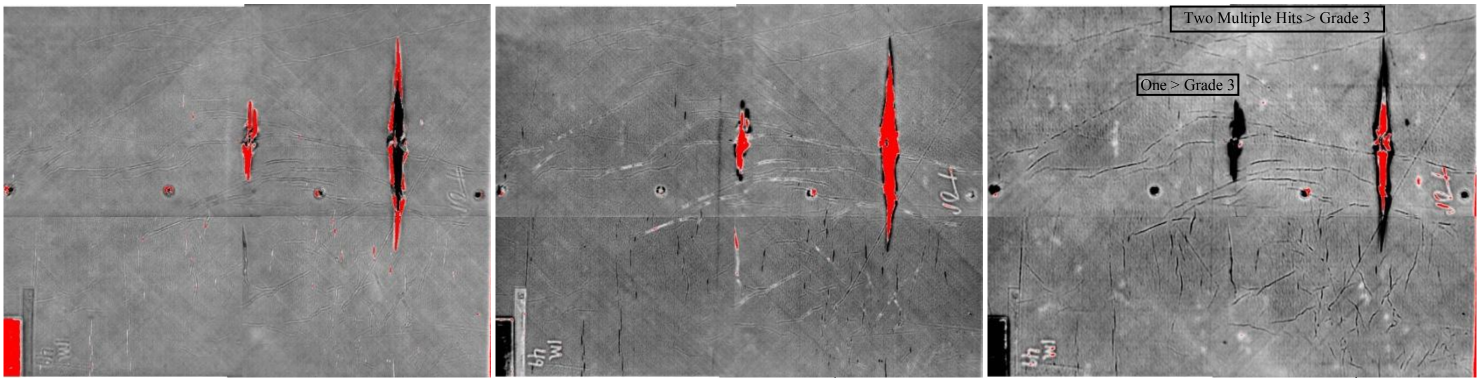


Figure 49. Post-Impact Thermography adhered Panel 49 {IM-93} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

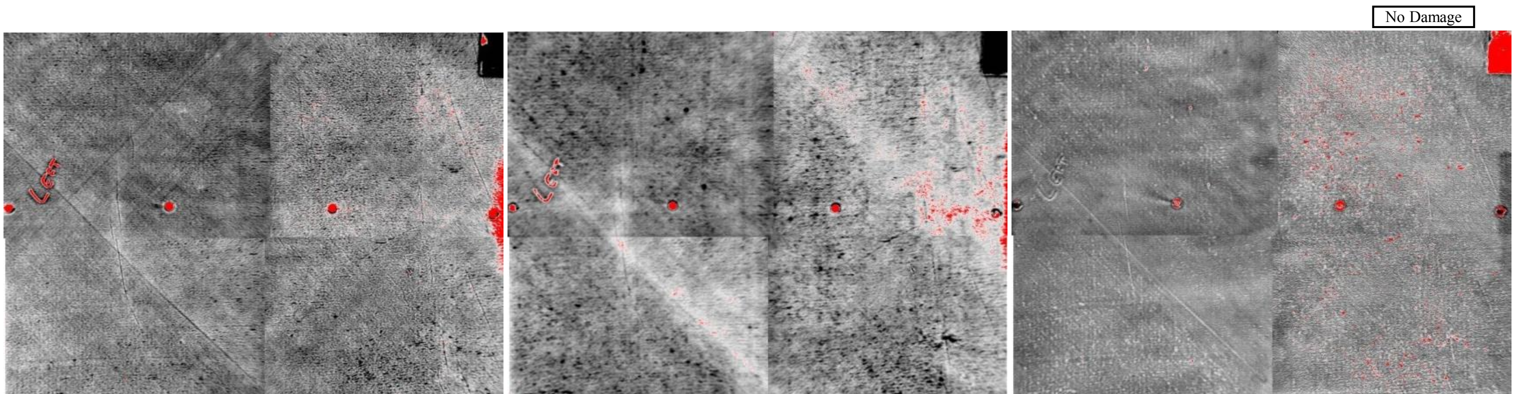


Figure 50. Post-Impact Thermography Panel 50 {IM-21} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

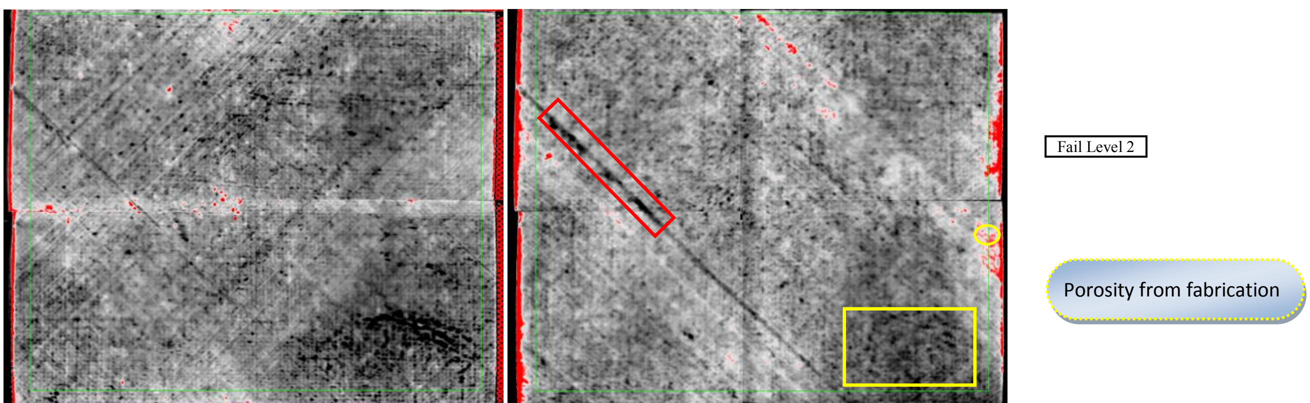


Figure 51. Thermography Panel 51 (1st Derv. - 0.42 & 0.94 sec) <mirrored from tool-side>

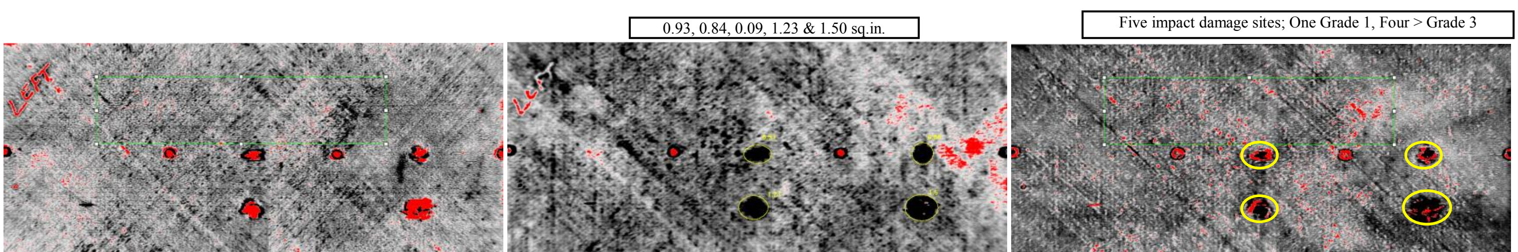


Figure 52. Post-Impact Thermography Panel 51 {MIM-1} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

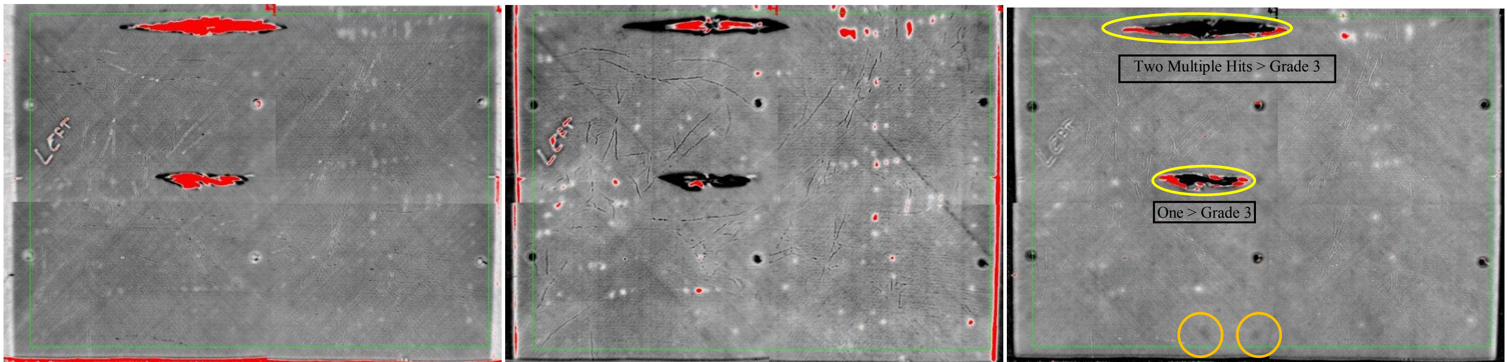


Figure 53. Post-Impact Thermography adhered Panel 52 {IM-90} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

Artifact from contact by coating layer damage

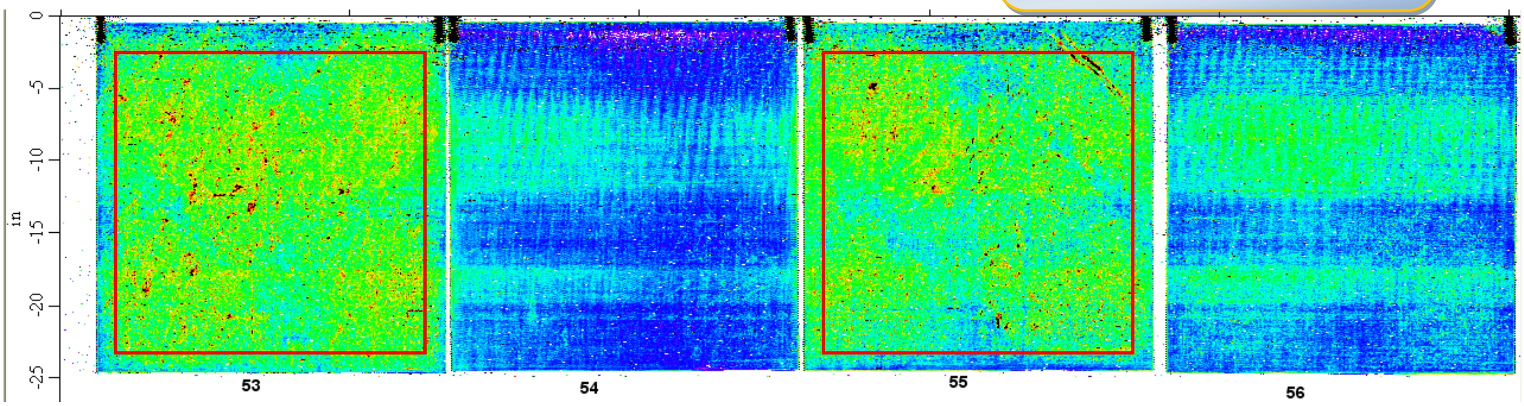


Figure 54. 5 MHz TTU Panel 53, 54, 55, 56

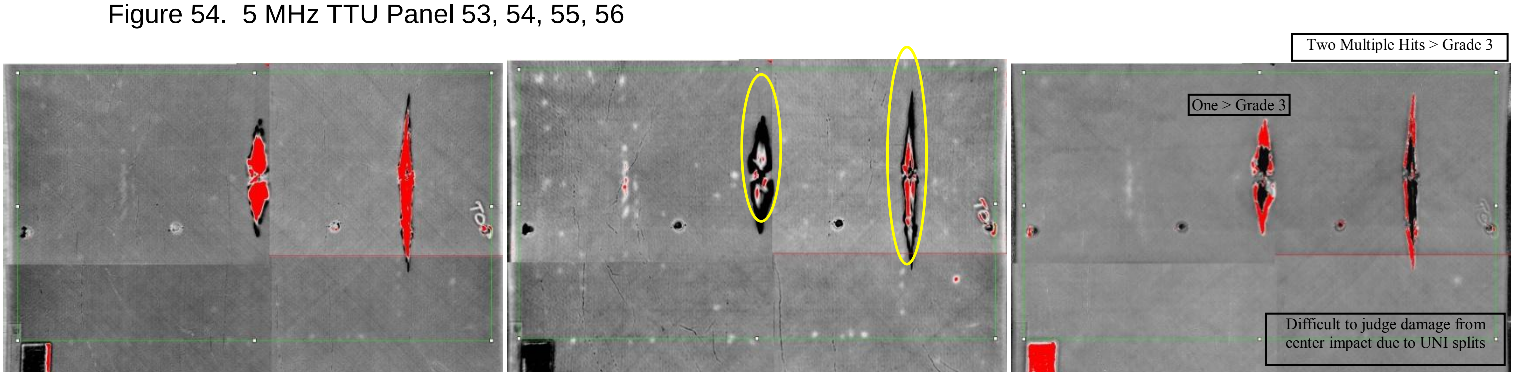


Figure 55. Post-Impact Thermography adhered Panel 54 {IM-92} (1st Derv. - 0.42, 0.94s & Peak Ampl)

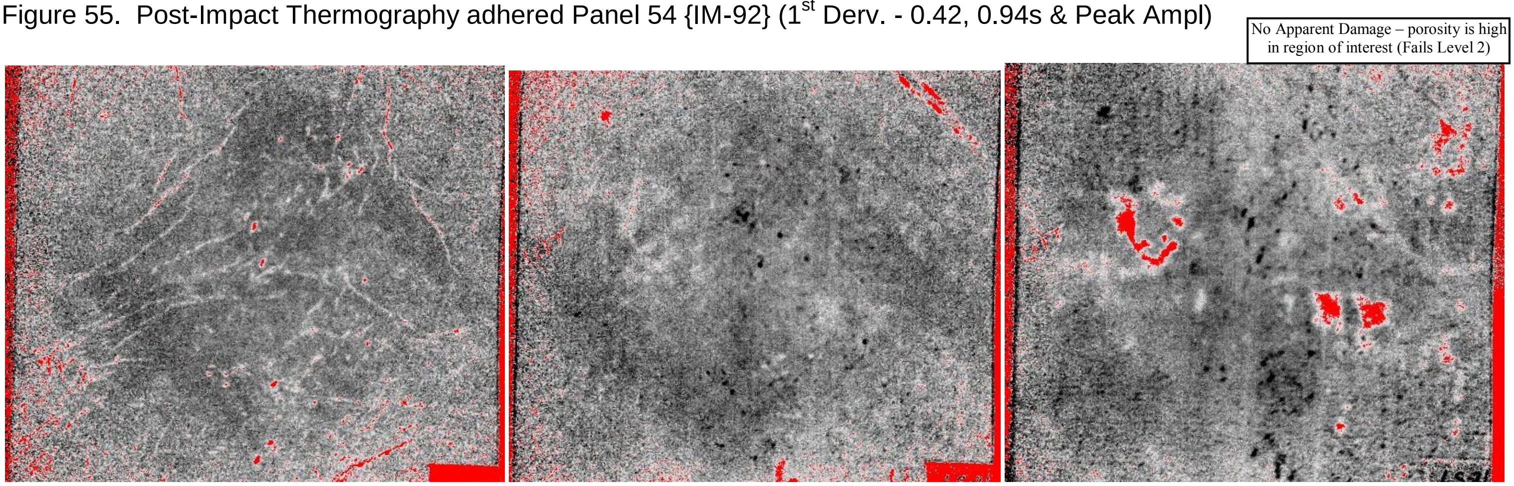
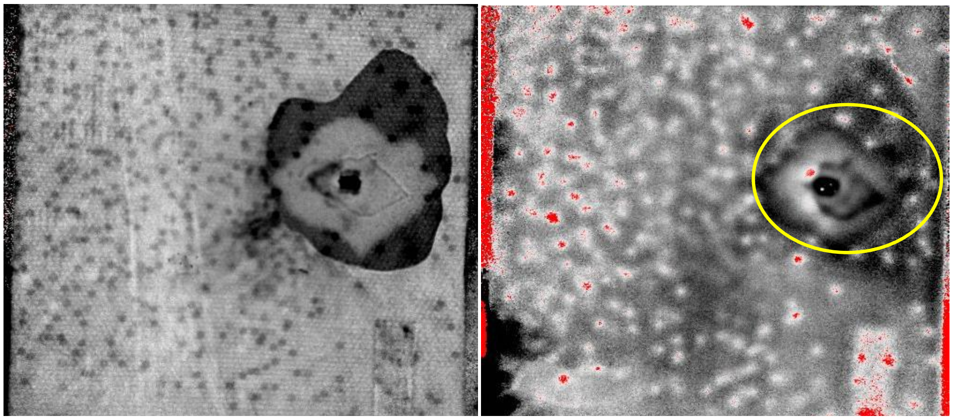


Figure 56. Post-Strike Thermography Back Panel 55 {LS-21} (1st Derv. – 0.08s, 0.42s, 0.94s)



Artifacts from contact by protective layer deformation

Figure 57. Post-Strike Thermography Front Panel 55 {LS-21} (1st Derv. – 0.4s & 8.66s)

Two Multiple Hits > Grade 3

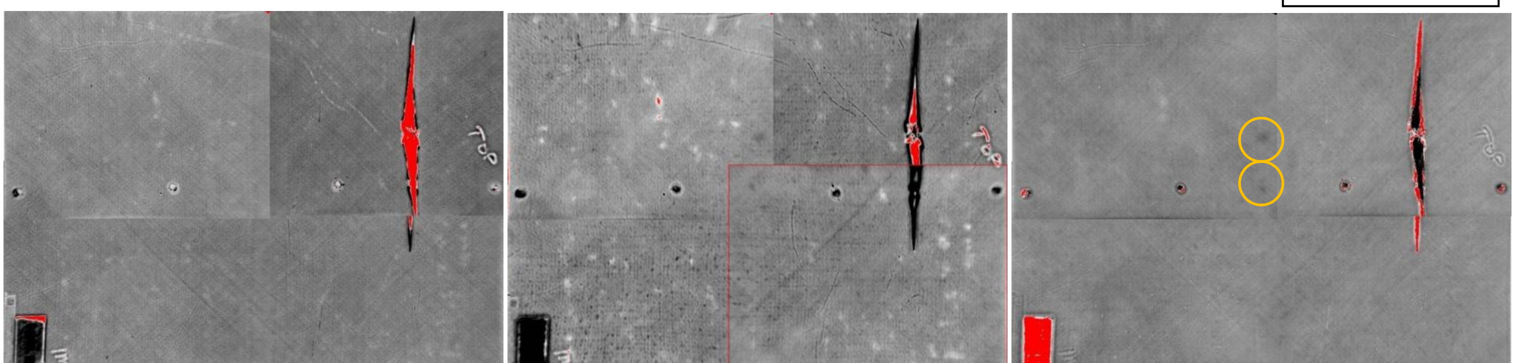


Figure 58. Post-Impact Thermography adhered Panel 56 {IM-61} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

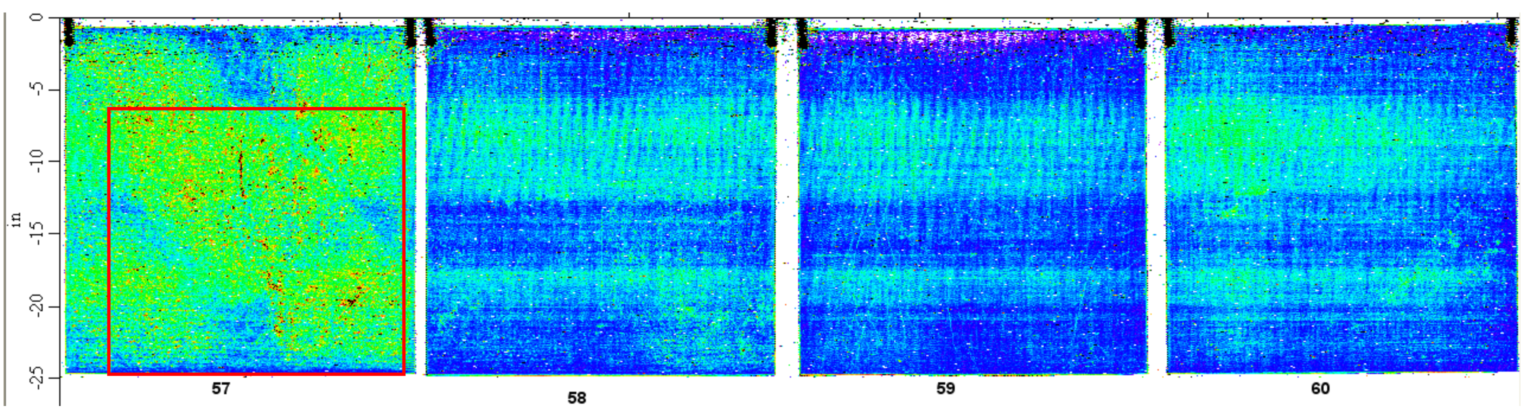


Figure 59. 5 MHz TTU Panel 57, 58, 59, 60

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

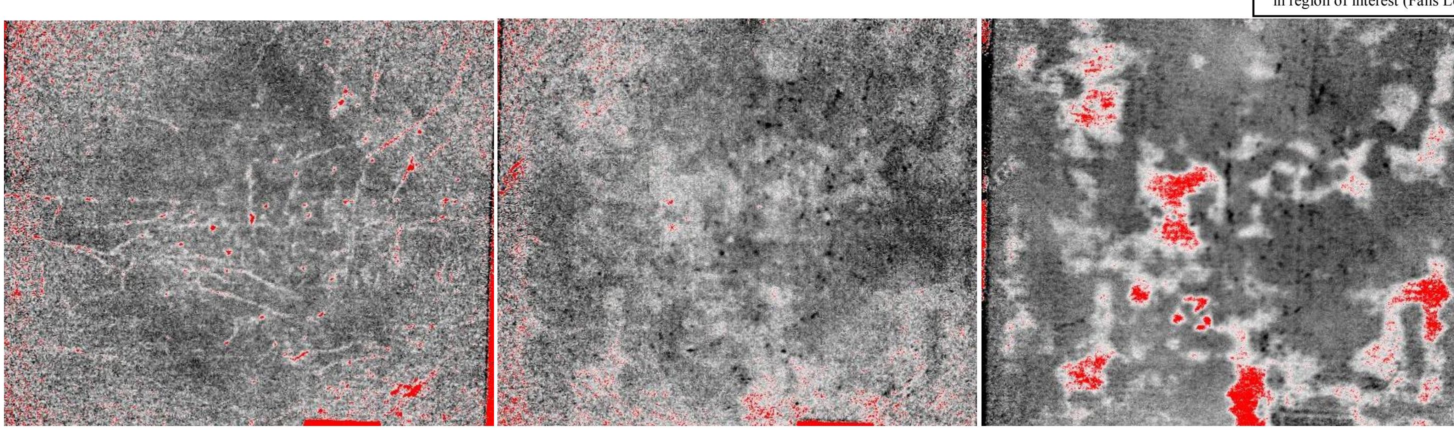


Figure 60. Post-Strike Thermography Back Panel 57 {LS-22} (1st Derv. – 0.08s, 0.42s, 0.94s)

3M debond

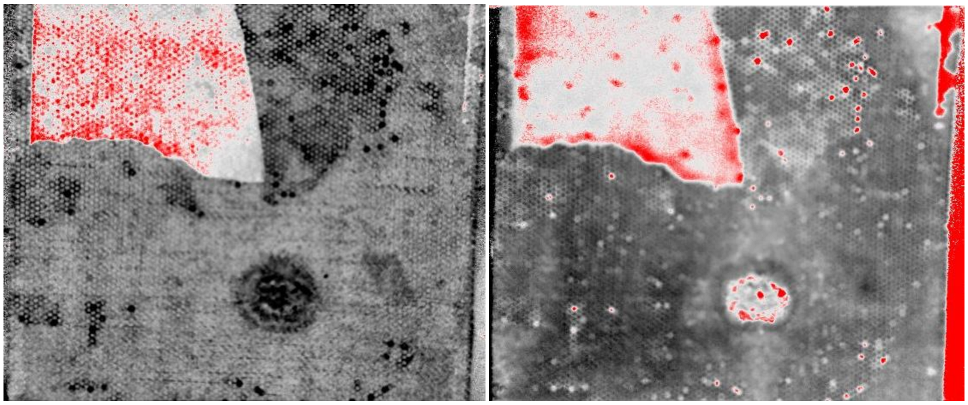


Figure 61. Post-Strike Thermography Front Panel 57 {LS-22} (1st Derv. – 0.4s & 8.66s)

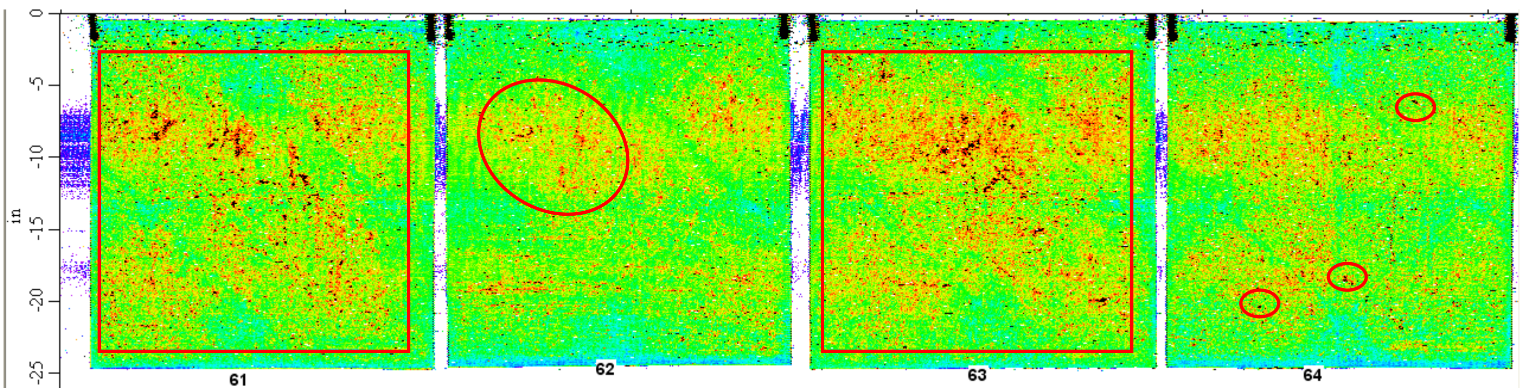


Figure 62. 5 MHz TTU Panel 61, 62, 63, 64

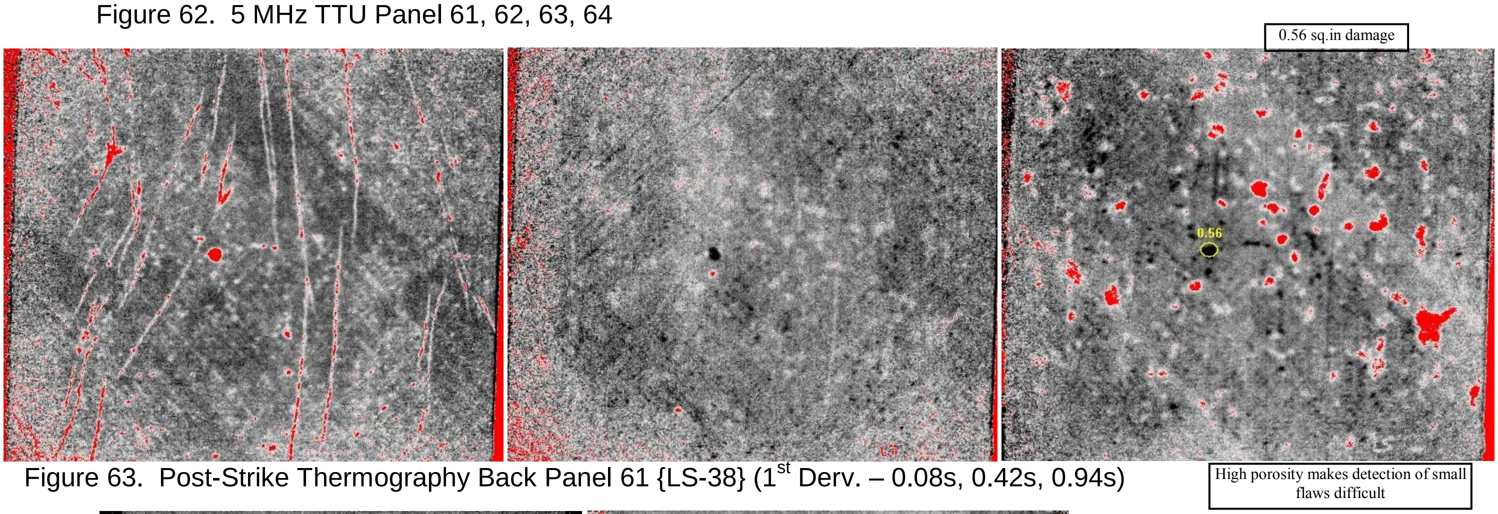


Figure 63. Post-Strike Thermography Back Panel 61 {LS-38} (1st Derv. – 0.08s, 0.42s, 0.94s)

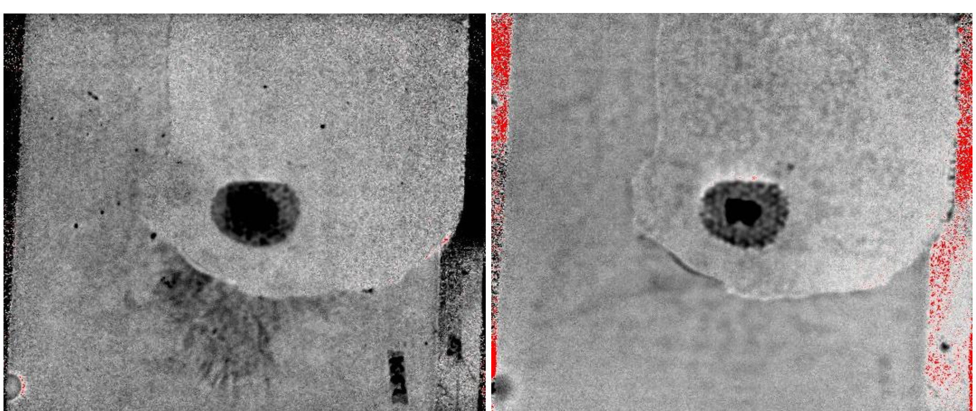


Figure 64. Post-Strike Thermography Front Panel 61 {LS-28} (1st Derv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

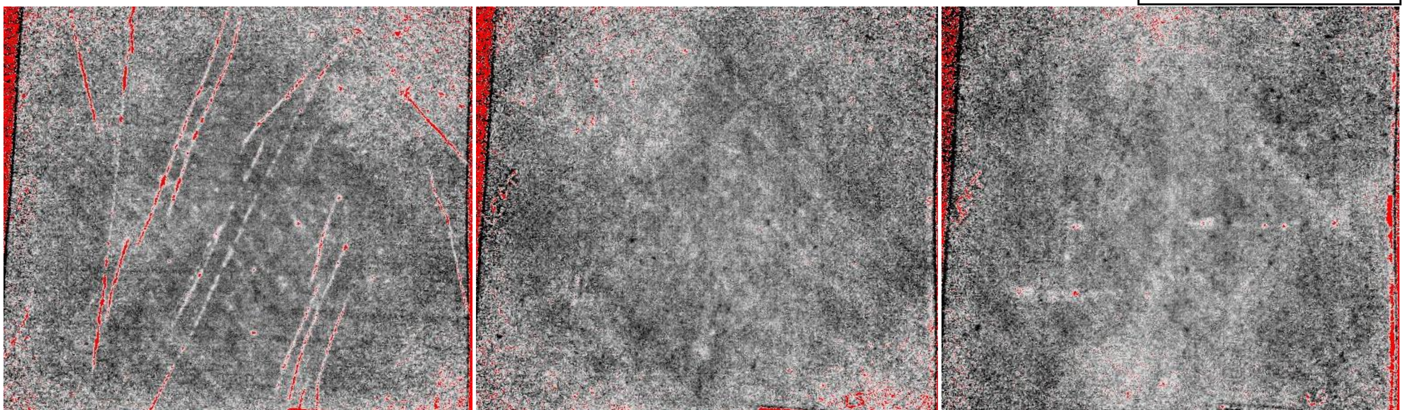


Figure 65. Post-Strike Thermography Back Panel 62 {LS-27} (1st Derv. – 0.08s, 0.42s, 0.94s)

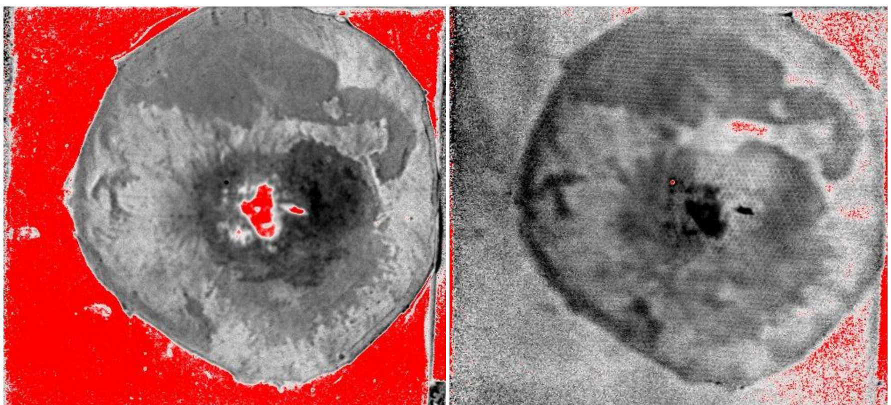


Figure 66. Post-Strike Thermography Front Panel 62 {LS-27} (1st Derv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

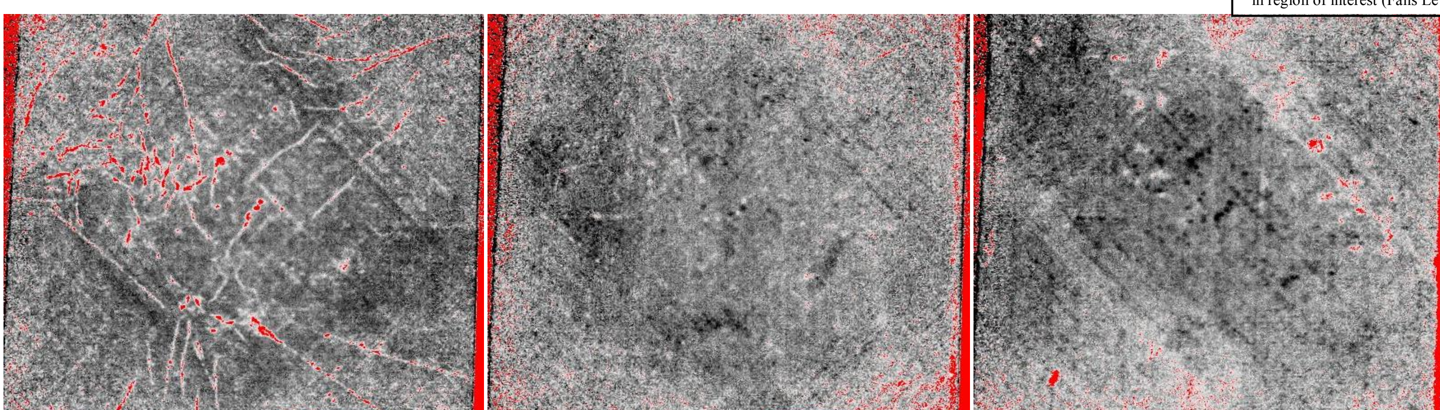


Figure 67. Post-Strike Thermography Back Panel 63 {LS-28} (1st Derv. – 0.08s, 0.42s, 0.94s)

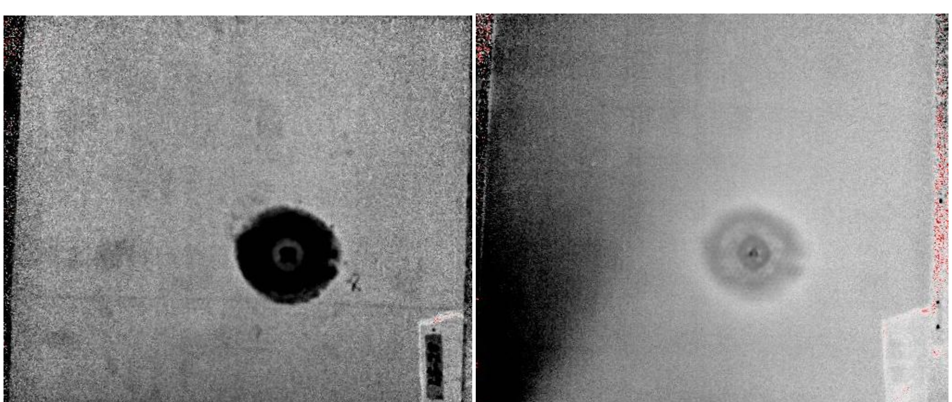


Figure 68. Post-Strike Thermography Front Panel 63 {LS-28} (1st Derv. – 0.4s & 8.66s)

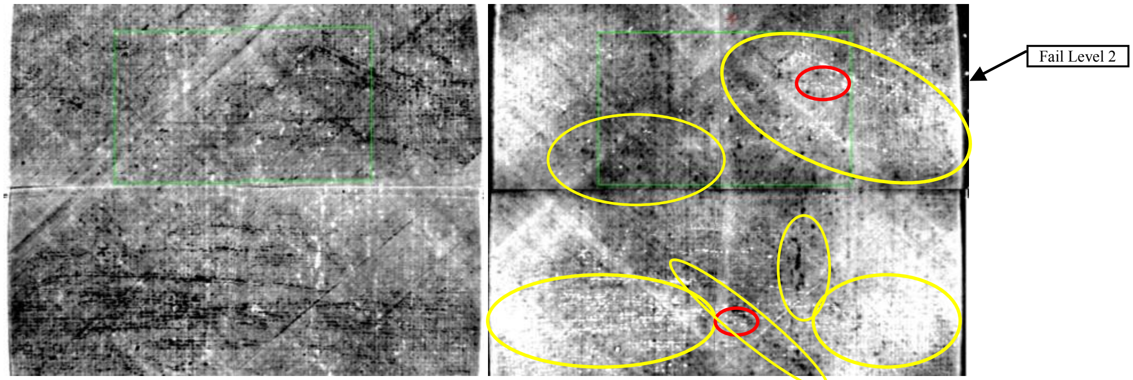


Figure 69. Thermography Panel 64 (1st Derv. - 0.3s & Peak Ampl.- Pos. 2nd Derv.)

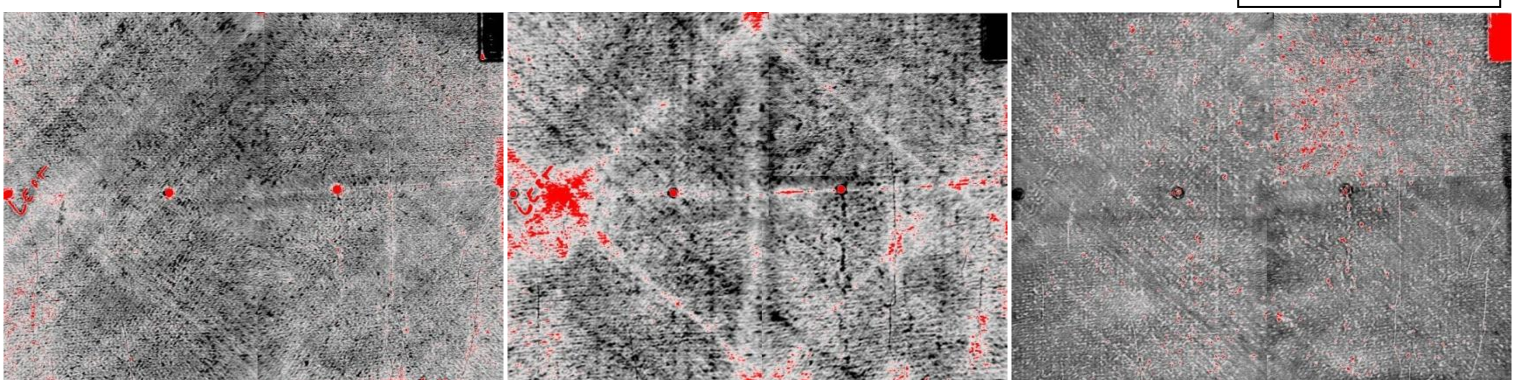


Figure 70. Post-Impact Thermography Panel 64 {IM-20} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

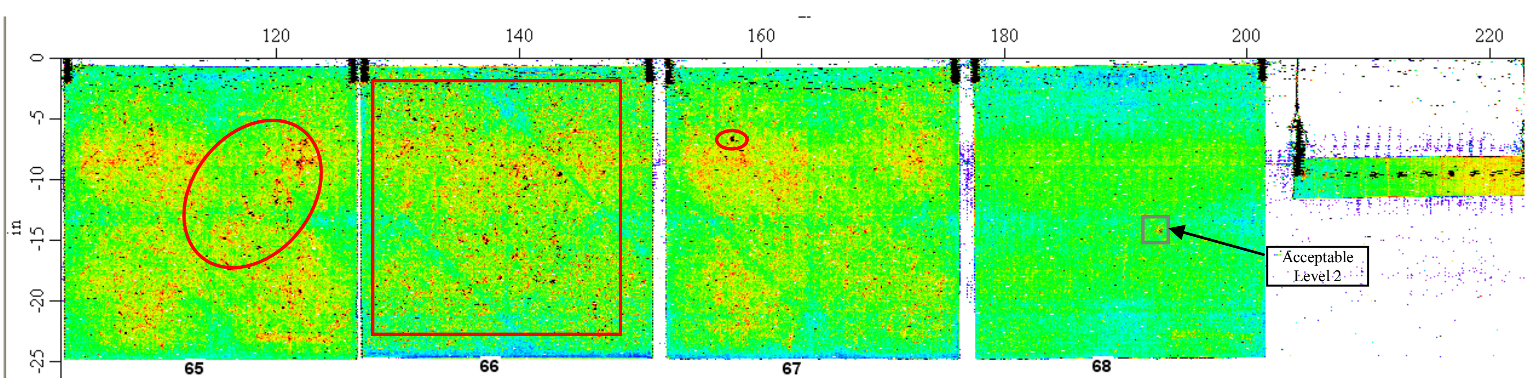


Figure 71. 5 MHz TTU Panel 65, 66, 67, 68

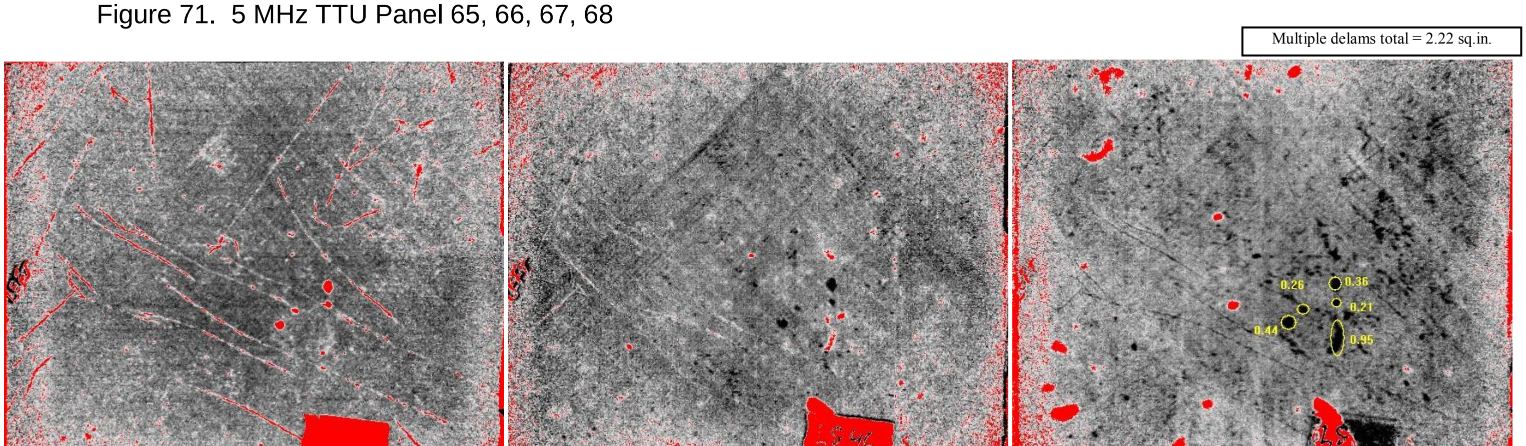


Figure 72. Post-Strike Thermography Back Panel 65 {LS-46} (1st Derv. – 0.08s, 0.42s, 0.94s)

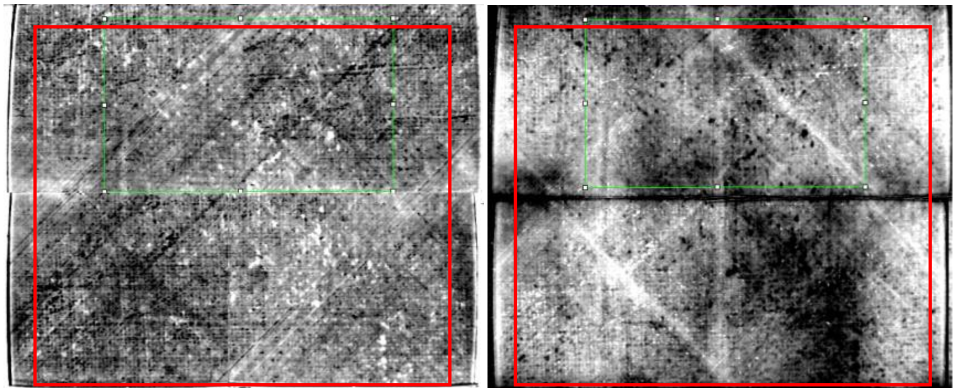


Figure 73. Thermography Panel 66 (1st Derv. - 0.3s & Peak Ampl.- Pos. 2nd Derv.)

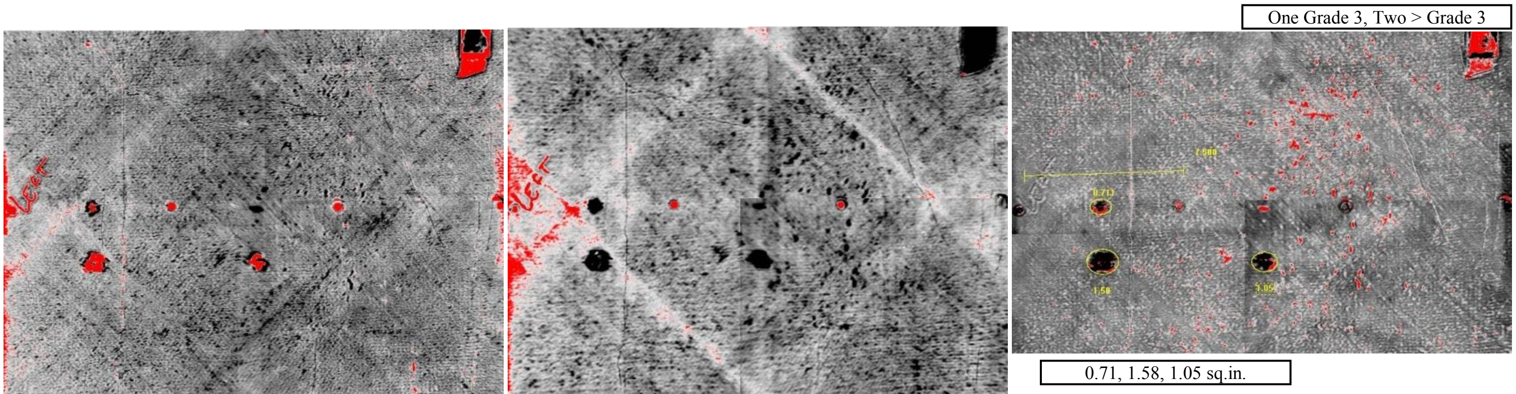


Figure 74. Post-Impact Thermography Panel 66 {IM-86} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

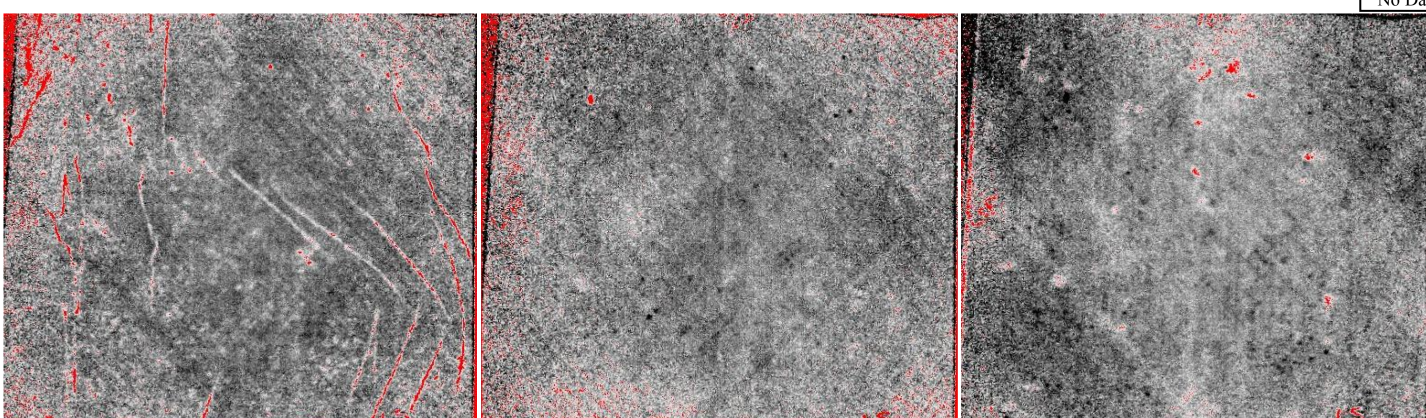


Figure 75. Post-Strike Thermography Back Panel 67 {LS-42} (1st Derv. – 0.08s, 0.42s, 0.94s)

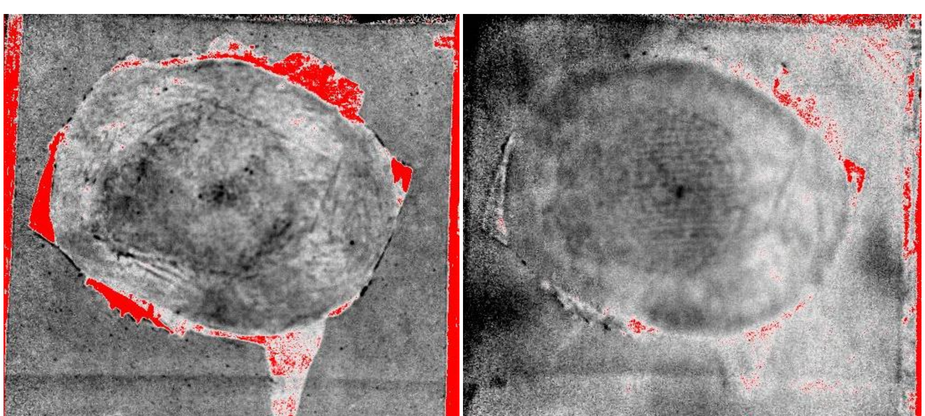


Figure 76. Post-Strike Thermography Front Panel 67 {LS-42} (1st Derv. – 0.4s & 8.66s)

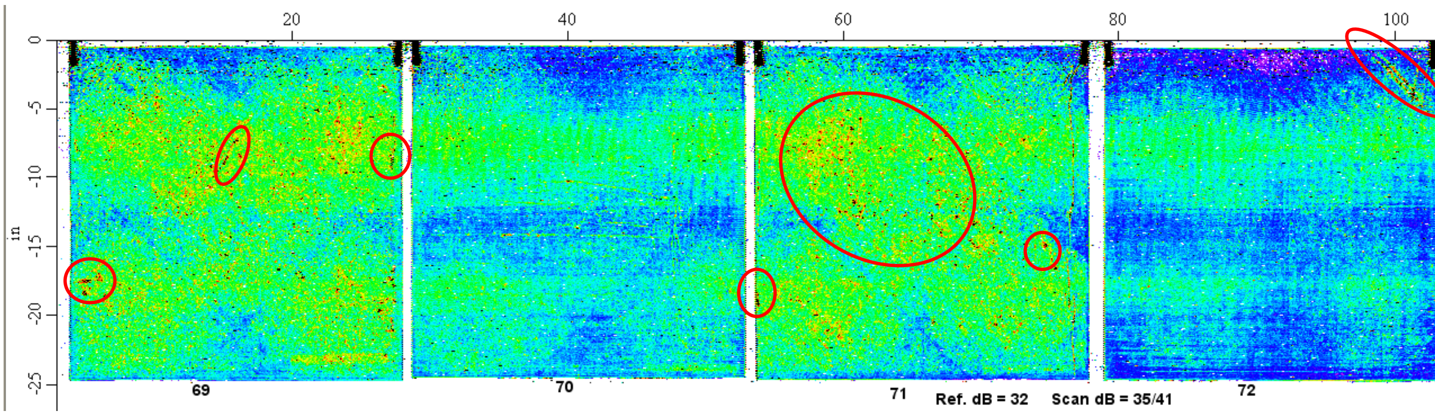


Figure 77. 5 MHz TTU Panel 69, 70, 71, 72

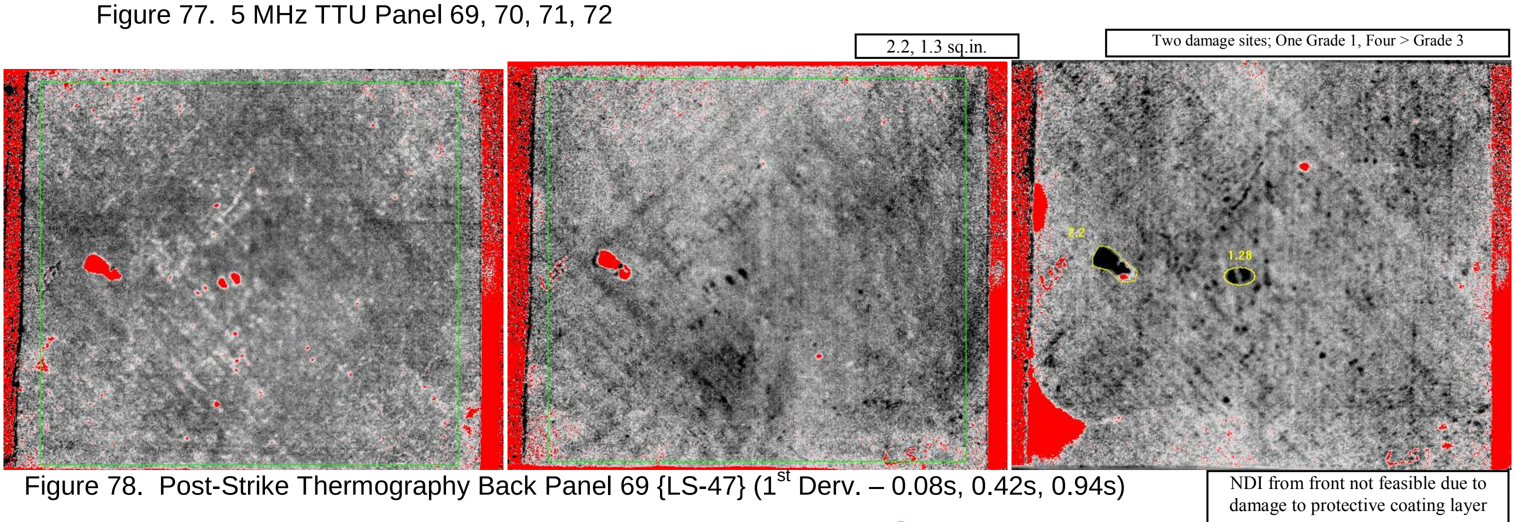


Figure 78. Post-Strike Thermography Back Panel 69 {LS-47} (1st Derv. – 0.08s, 0.42s, 0.94s)

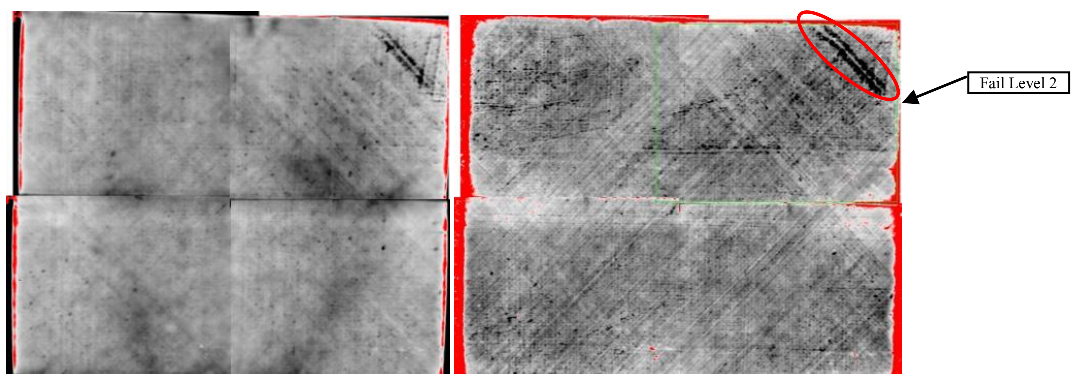


Figure 79. Thermography Panel 72 (1st Derv. - 0.42 & 0.94 sec)

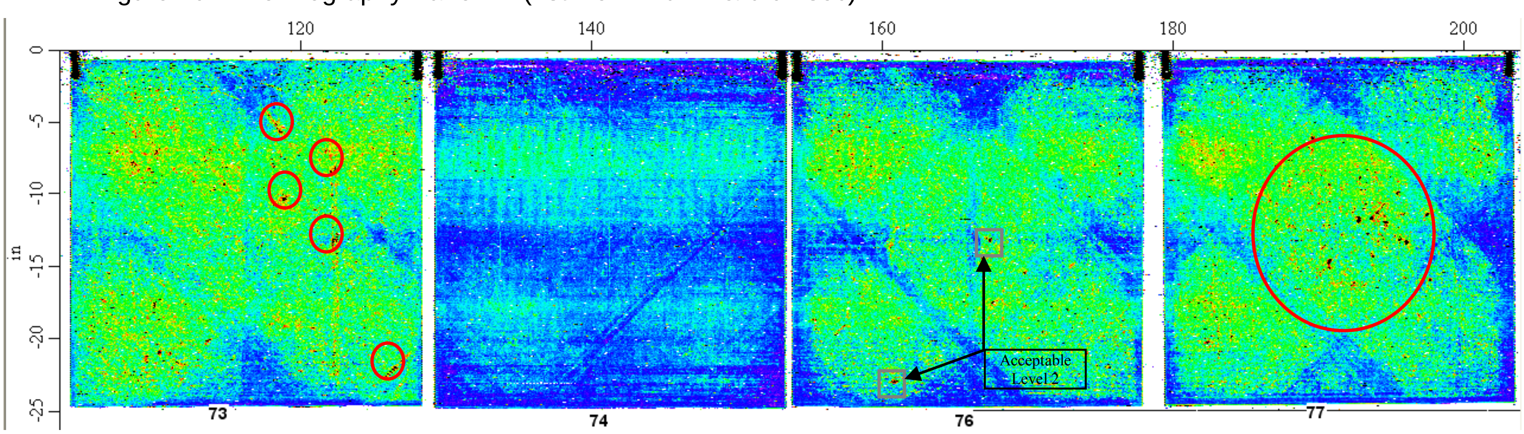


Figure 80. 5 MHz TTU Panel 73, 74, 76, 77

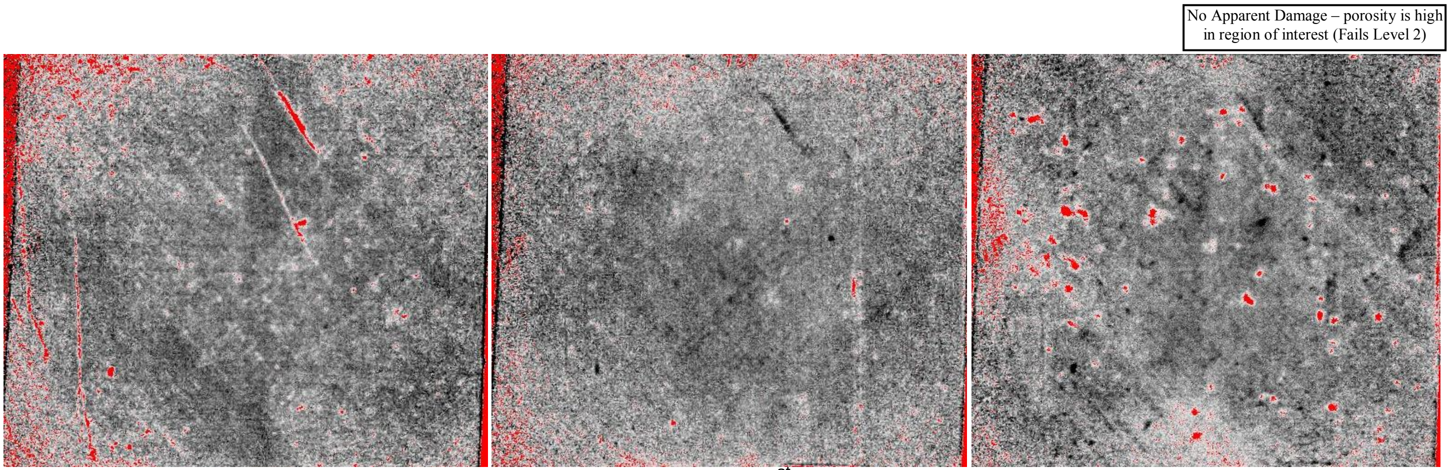


Figure 81. Post-Strike Thermography Back Panel 73 {LS-37} (1st Derv. – 0.08s, 0.42s, 0.94s)

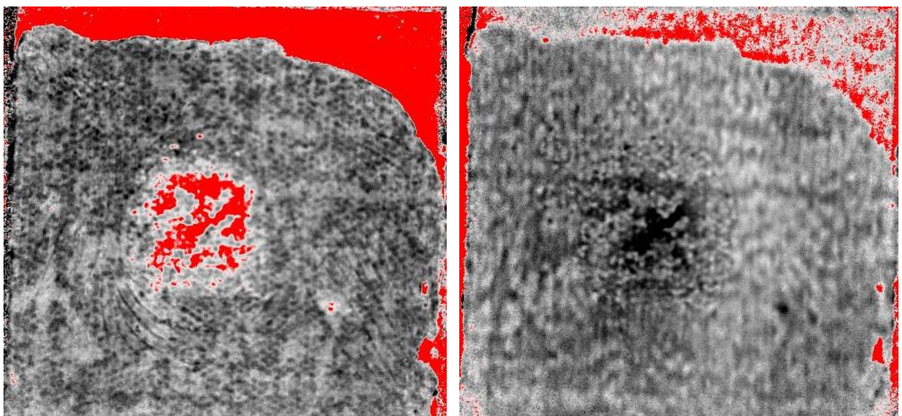


Figure 82. Post-Strike Thermography Front Panel 73 {LS-37} (1st Derv. – 0.4s & 8.66s)

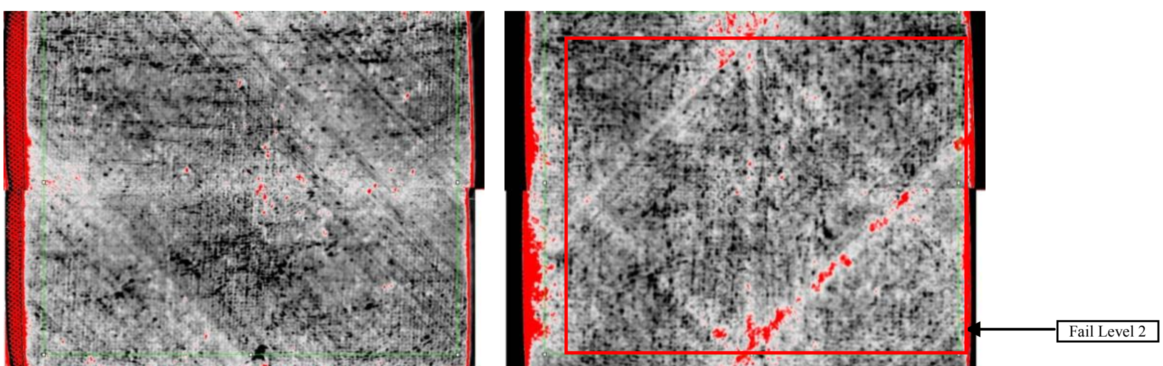


Figure 83. Thermography Panel 75 (1st Derv. - 0.42 & 0.94 sec)

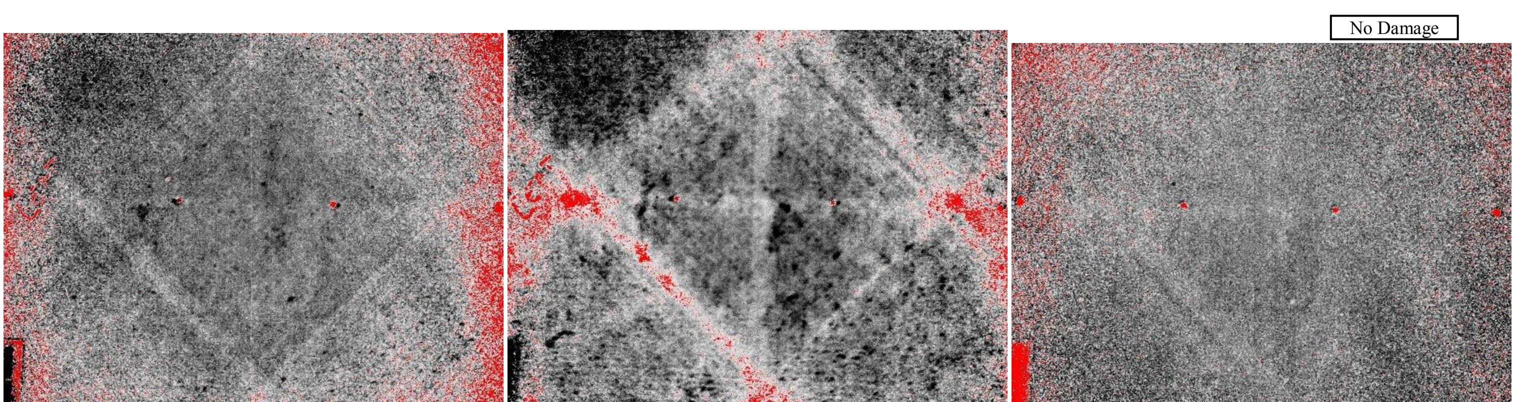


Figure 84. Post-Impact Thermography Panel 76 {IM-38} (1st Derv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Derv.)

No Damage

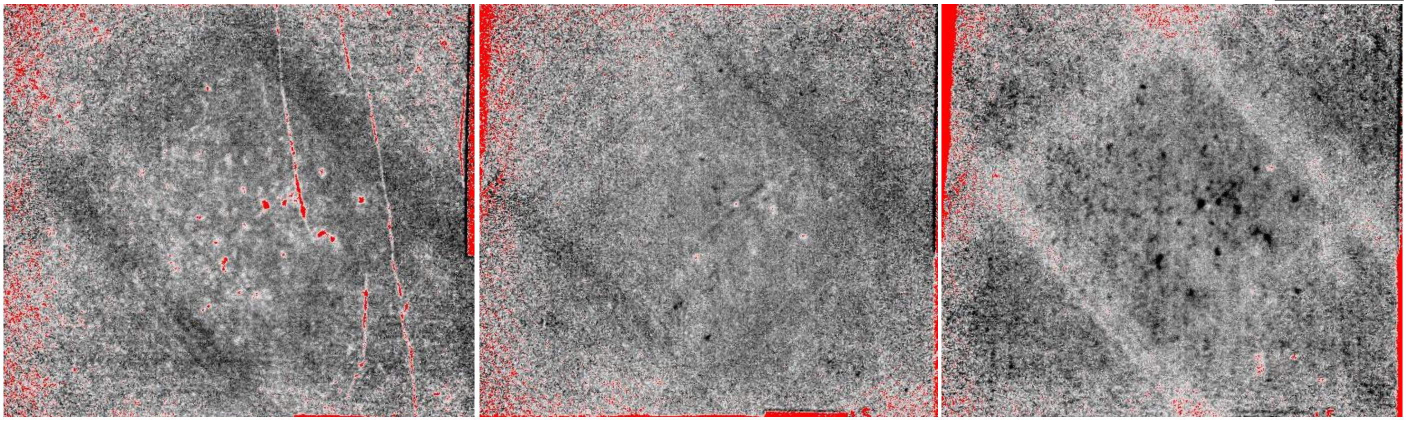
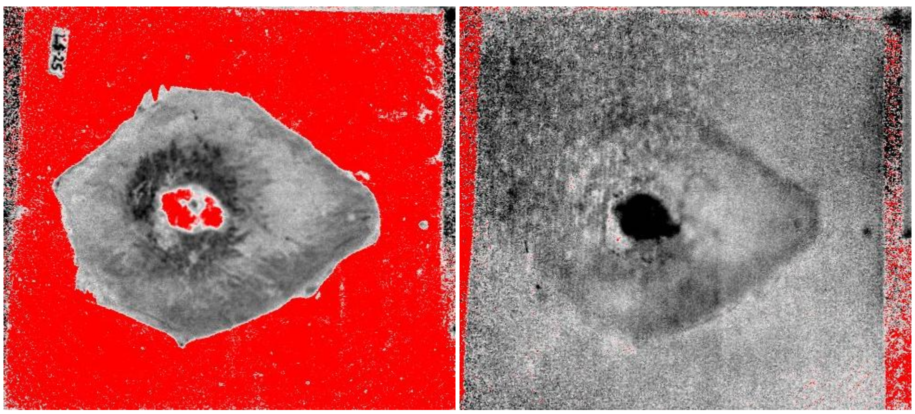


Figure 85a. Post-Strike Thermography Back Panel 77 {LS-25} (1st Derv. – 0.08s, 0.42s, 0.94s)



Protective Coating Delam

Figure 85b. Post-Strike Thermography Front Panel 77 {LS-25} (1st Deriv. – 0.4s & 8.66s)

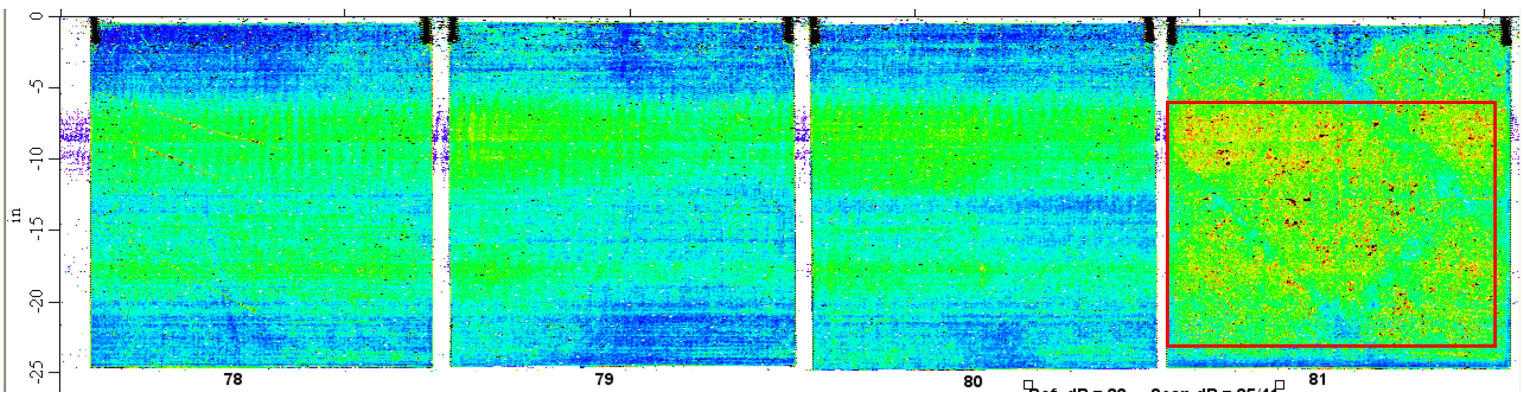


Figure 86. 5 MHz TTU Panel 78, 79, 80, 81

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

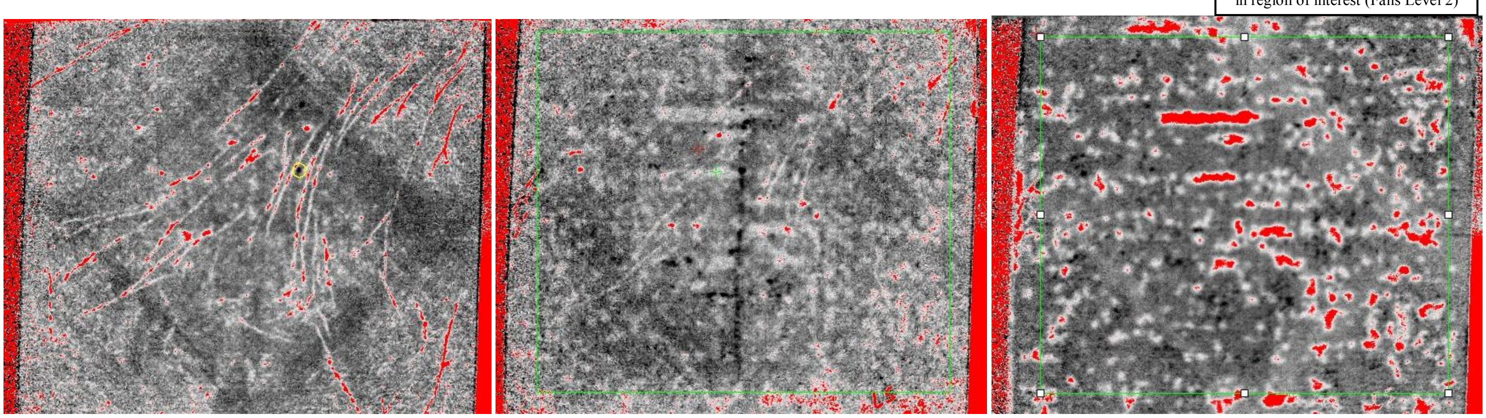


Figure 87. Post-Strike Thermography Back Panel 81 {LS-39} (1st Deriv. – 0.08s, 0.42s, 0.94s)

Porosity from fabrication

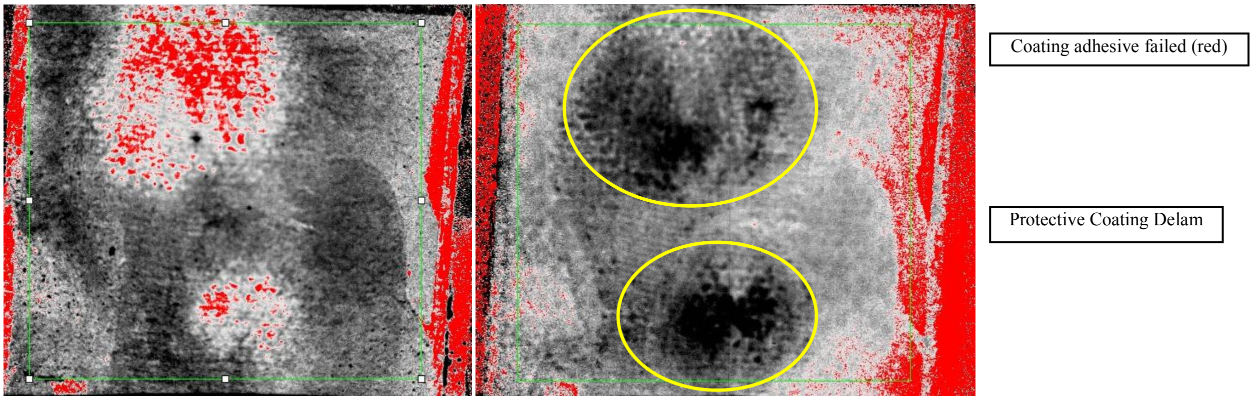


Figure 88. Post-Strike Thermography Front Panel 81 {LS-39} (1st Deriv. – 0.4s & 8.66s)

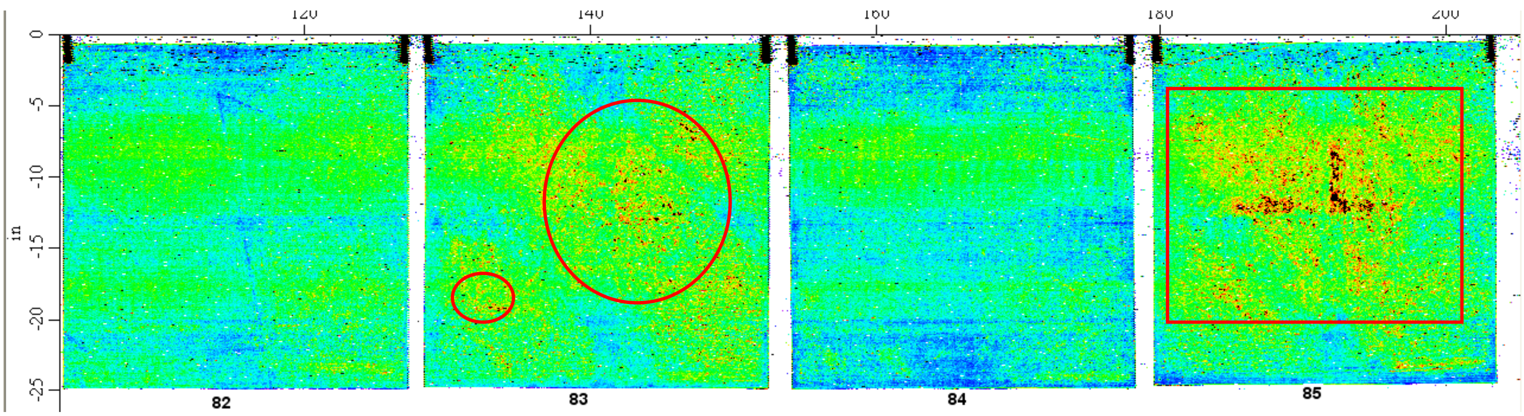


Figure 89. 5 MHz TTU Panel 82, 83, 84, 85

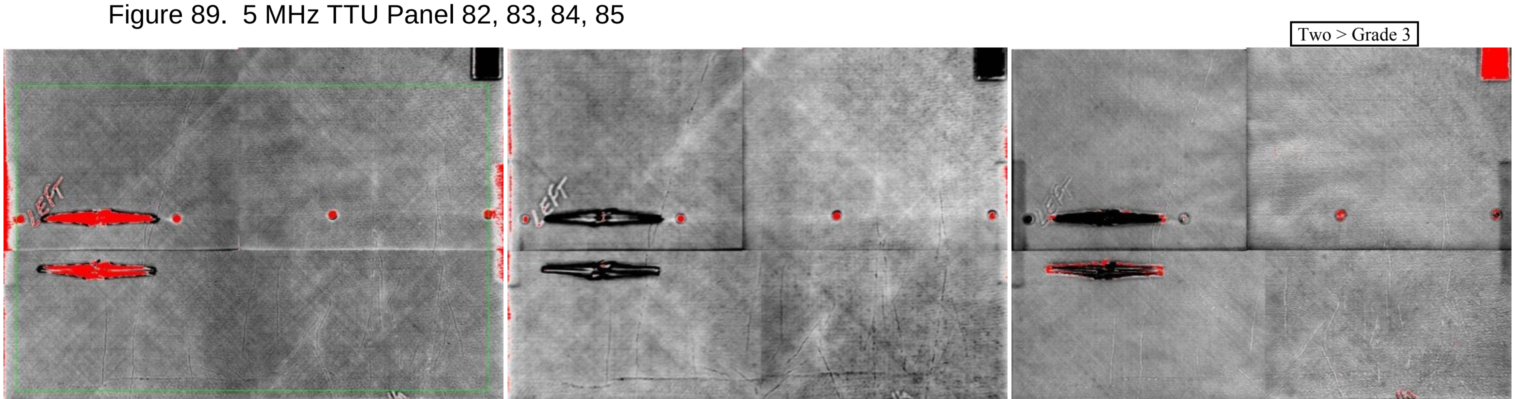


Figure 90. Post-Impact Thermography Panel 82 {IM-53} (1st Deriv. - 0.42, 0.94s & Peak Ampl.)

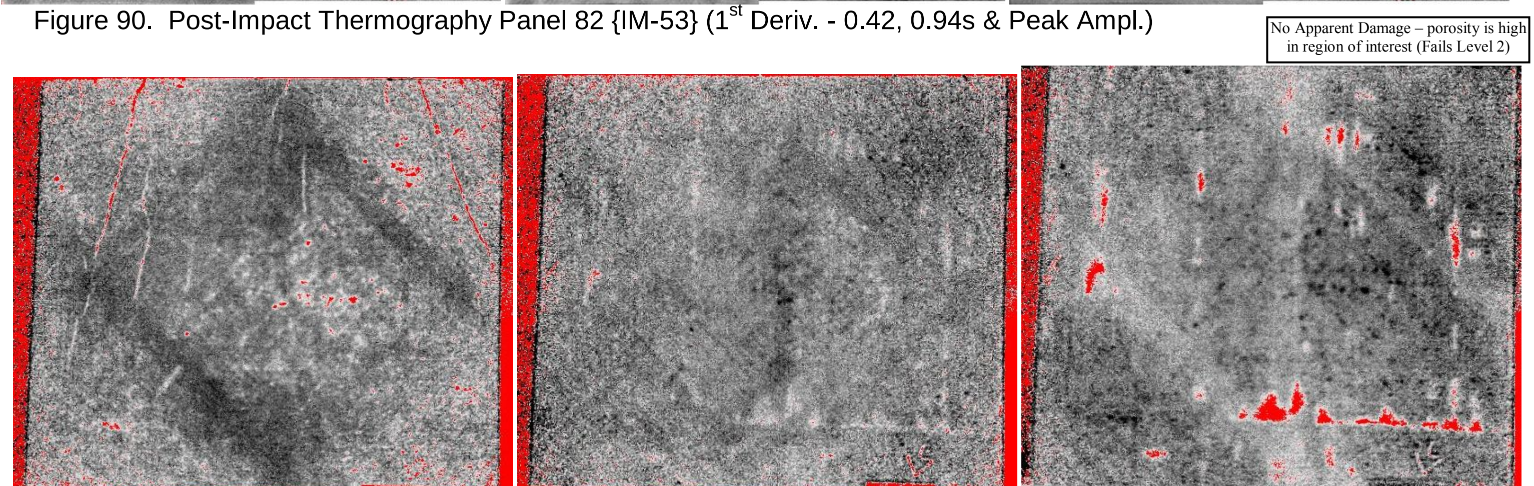


Figure 91. Post-Strike Thermography Back Panel 83 {LS-9} (1st Deriv. – 0.08s, 0.42s, 0.94s)

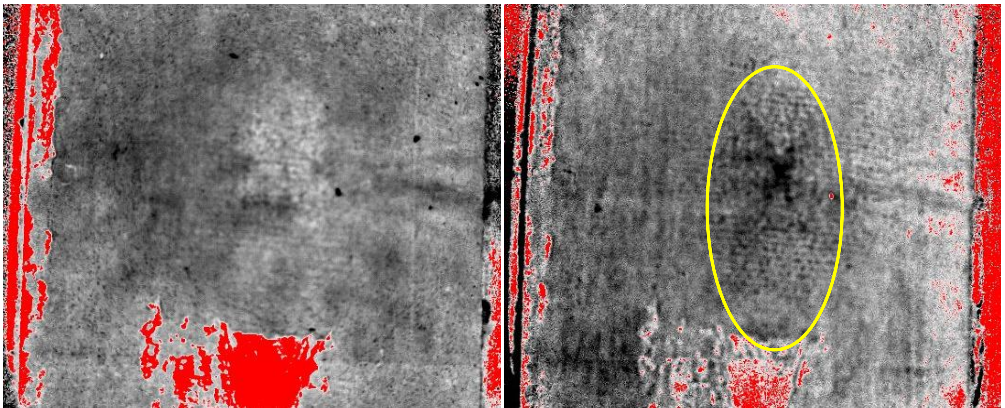


Figure 92. Post-Strike Thermography Front Panel 83 {LS-9} (1st Deriv. – 0.4s & 8.66s)

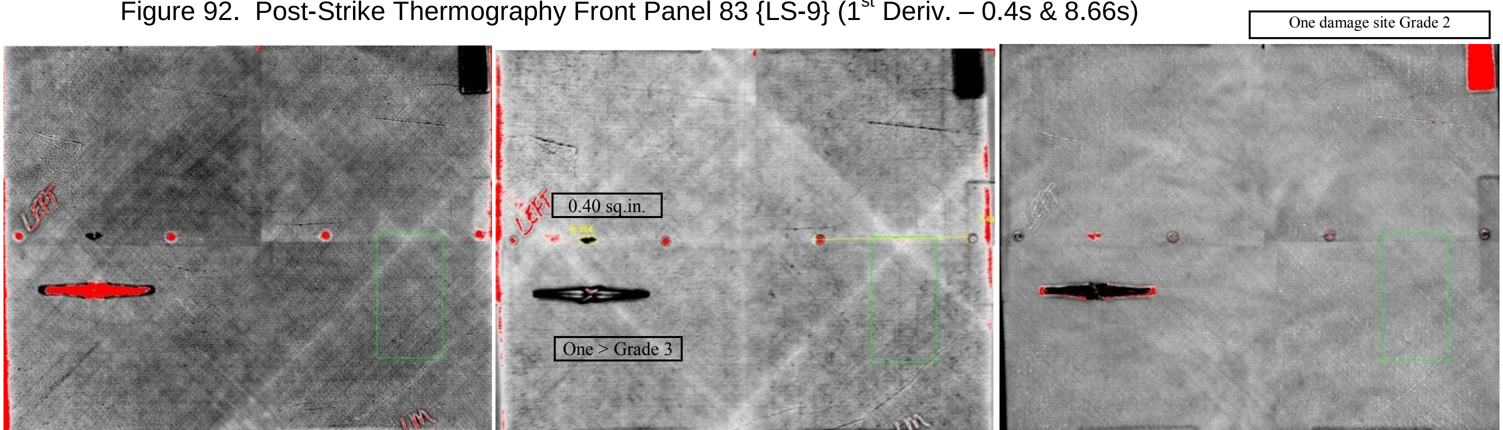


Figure 93. Post-Impact Thermography Panel 84 {IM-54} (1st Deriv. - 0.42, 0.94s & Peak Ampl)

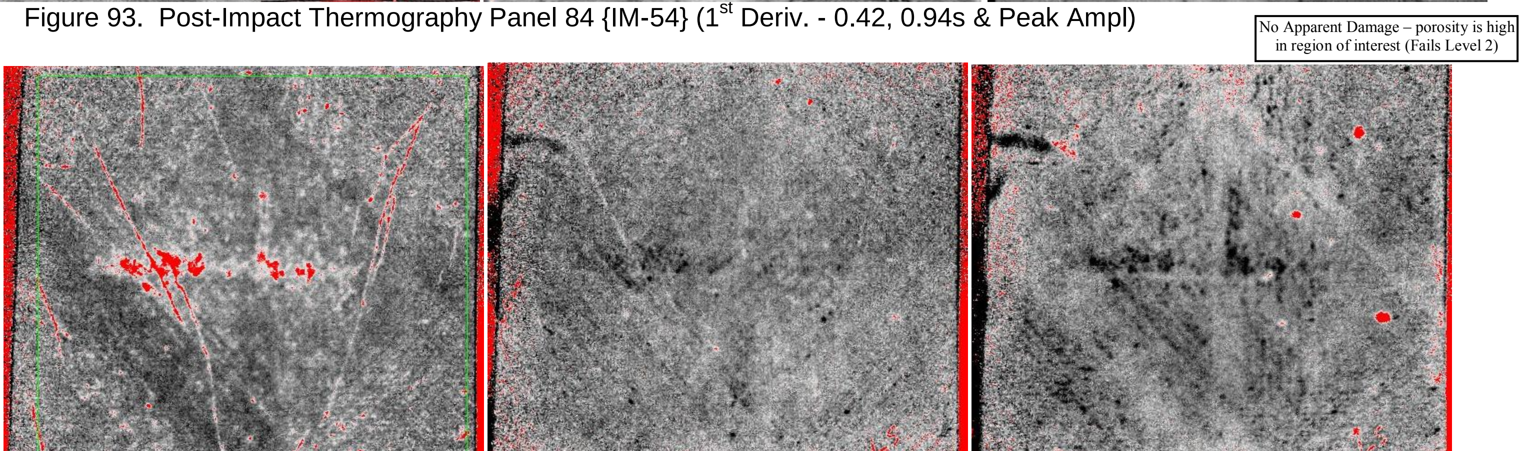


Figure 94. Post-Strike Thermography Back Panel 85 {LS-18} (1st Deriv. – 0.08s, 0.42s, 0.94s)

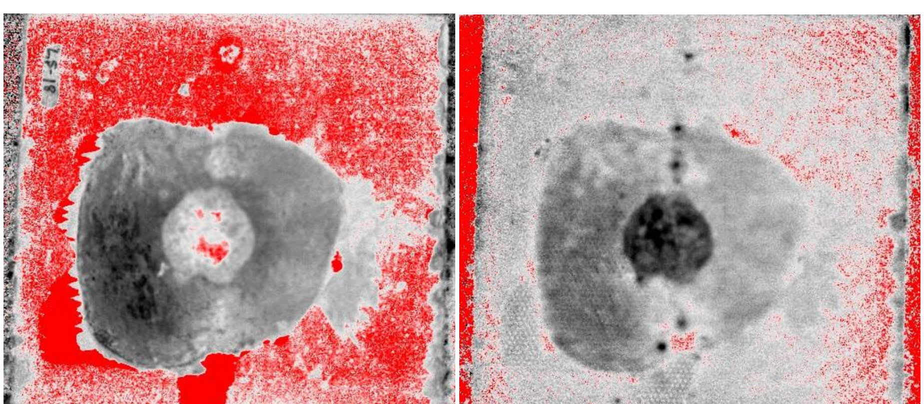


Figure 95. Post-Strike Thermography Front Panel 85 {LS-18} (1st Deriv. – 0.4s & 8.66s)

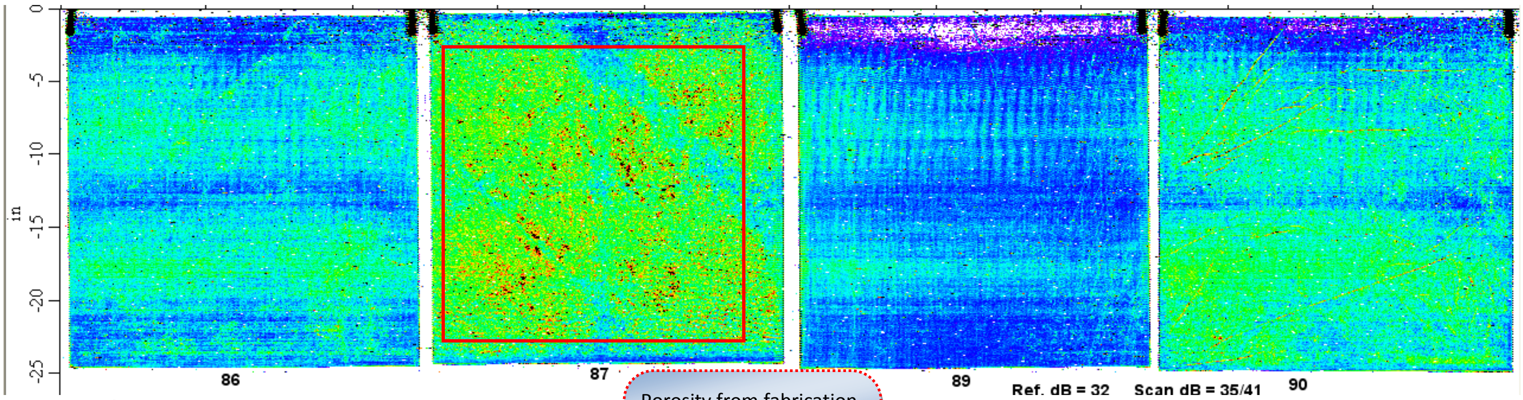


Figure 96. 5 MHz TTU Panel 86, 87, 89, 90

Porosity from fabrication

4.8 sq.in. lam damage > Grade 3

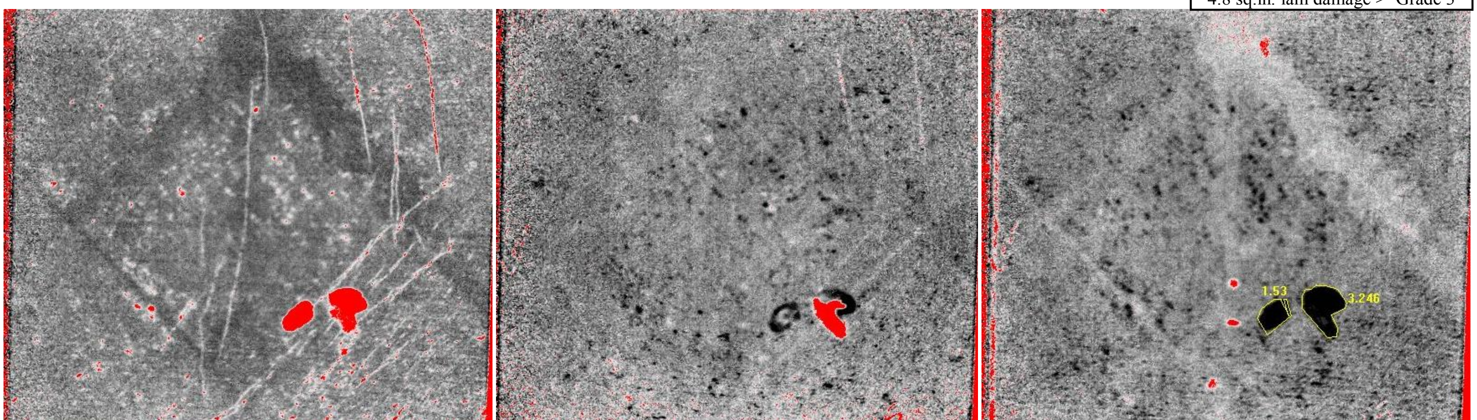


Figure 97. Post-Strike Thermography Back Panel 87 {LS-20} (1st Deriv. – 0.08s, 0.42s, 0.94s)

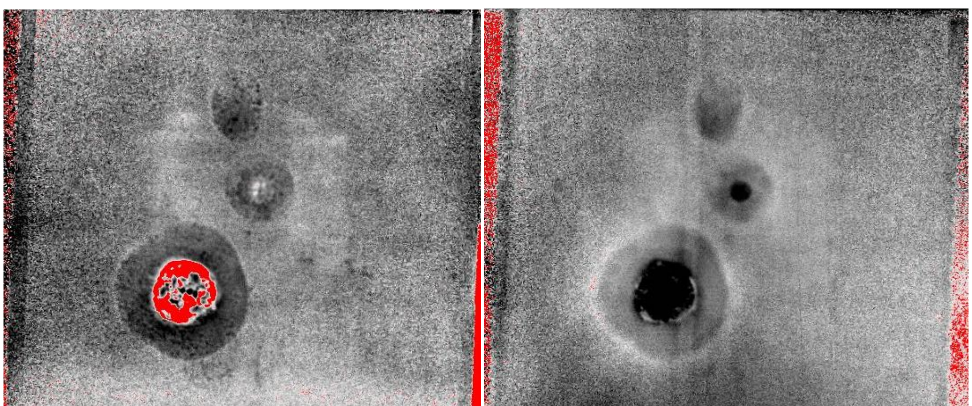


Figure 98. Post-Strike Thermography Front Panel 87 {LS-20} (1st Deriv. – 0.4s & 8.66s)

No Damage

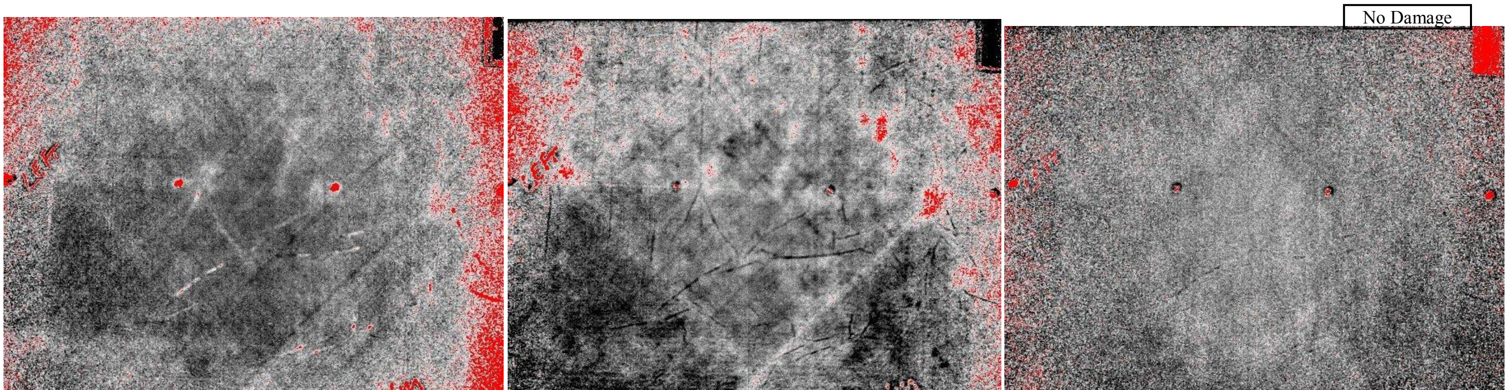


Figure 99. Post-Impact Thermography Panel 86 {IM-43} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

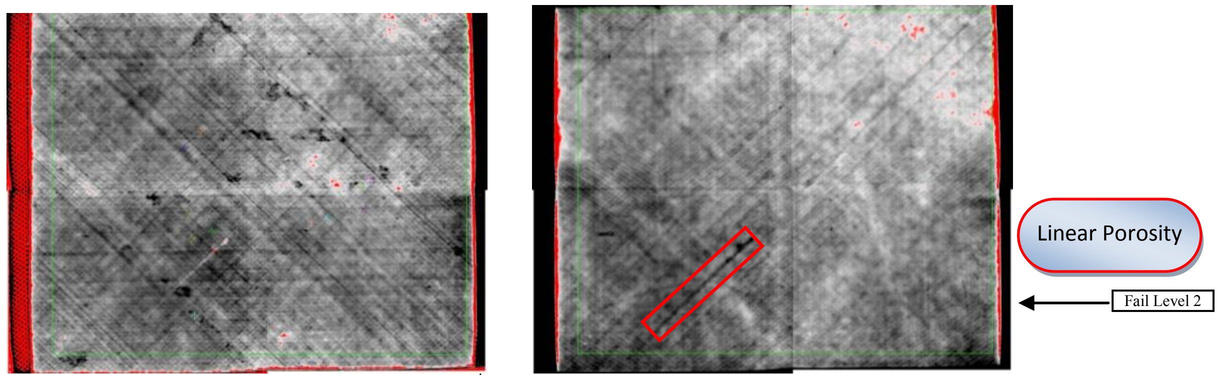


Figure 100. Thermography Panel 88 (1^{st} Deriv. - 0.42 & 0.94 sec)

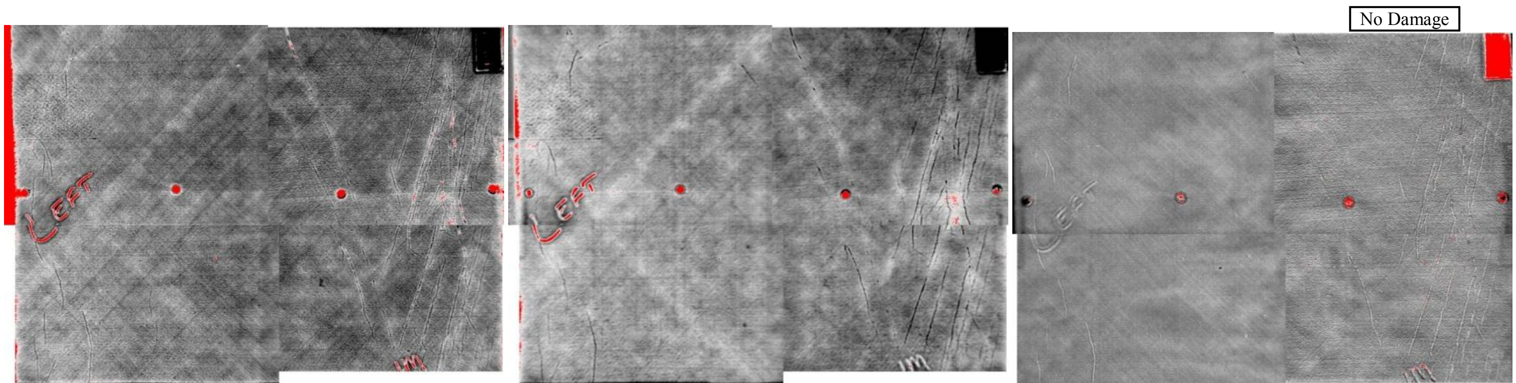


Figure 101. Post-Impact Thermography Panel 89 {IM-40} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

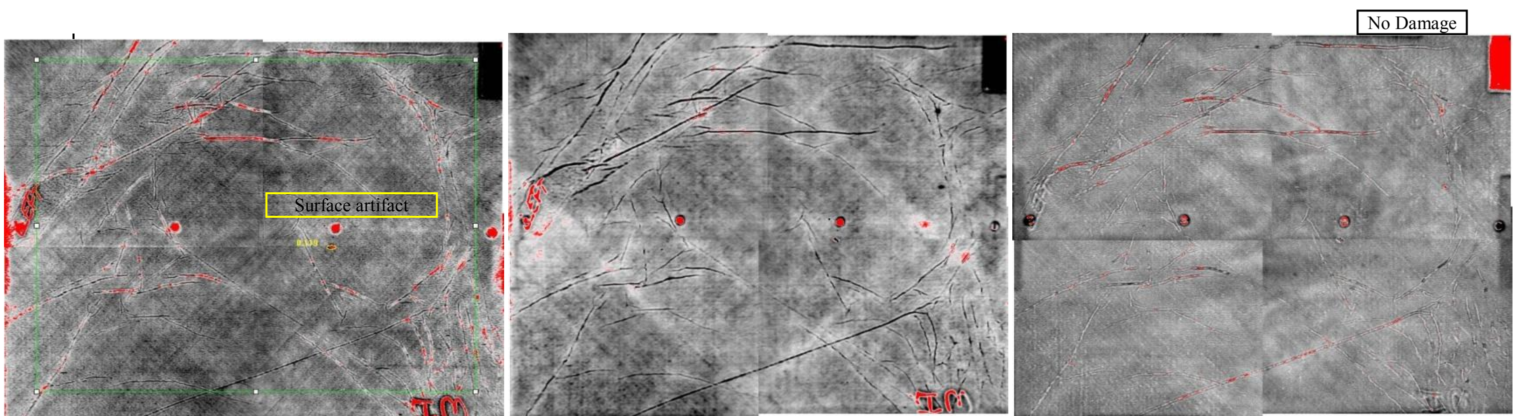


Figure 102. Post-Impact Thermography Panel 90 {IM-29} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

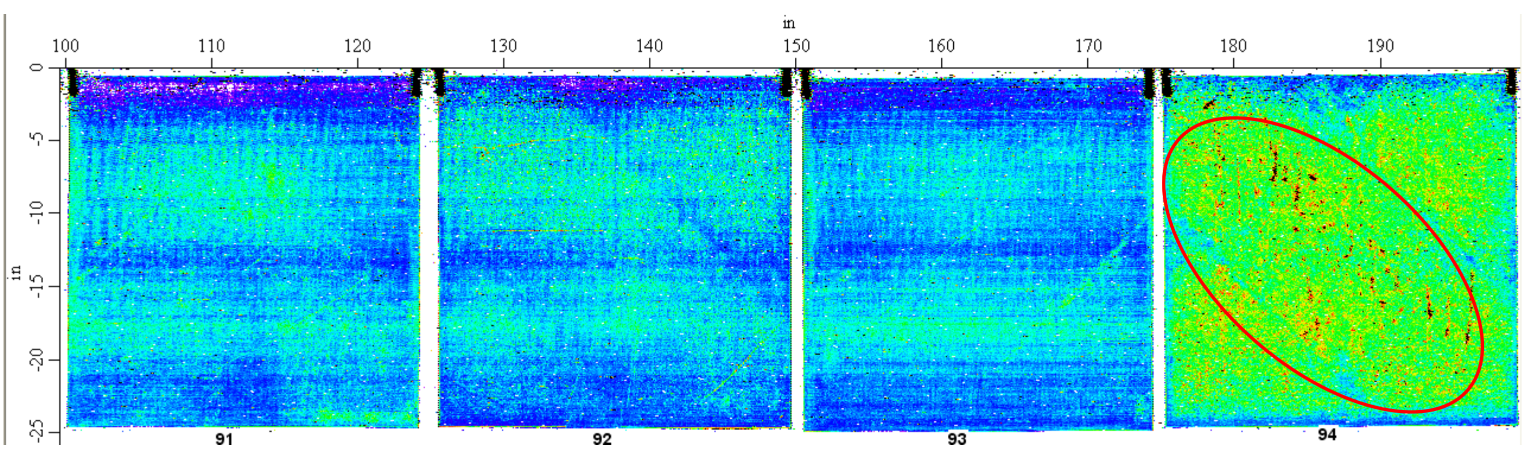


Figure 103. 5 MHz TTU Panel 91, 92, 93, 94

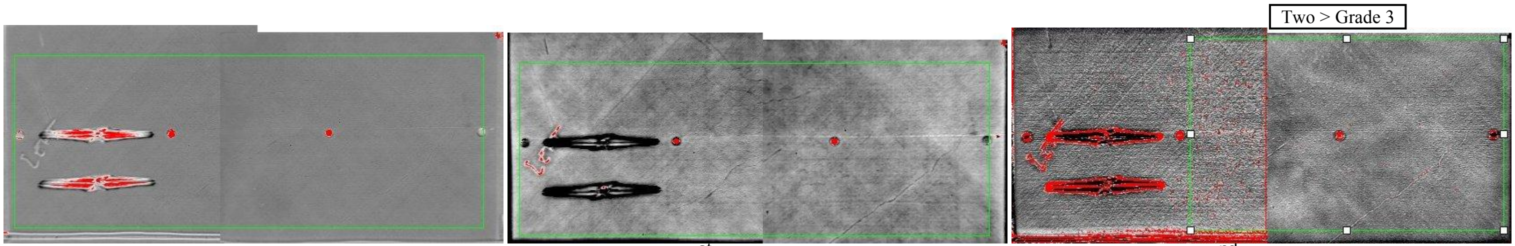


Figure 104. Post-Impact Thermography Panel 91 {IM-48} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

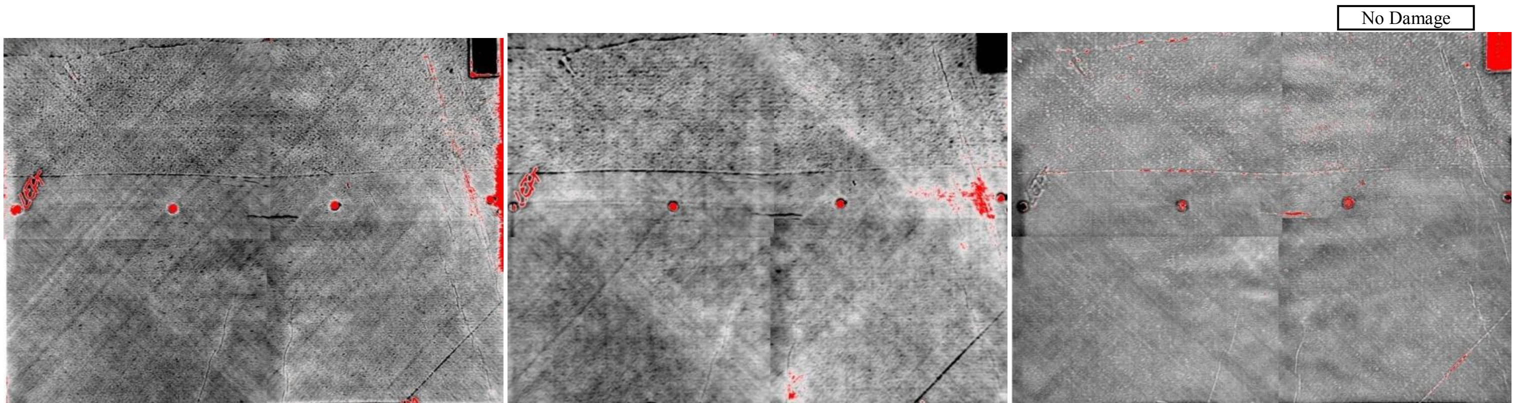


Figure 105. Post-Impact Thermography Panel 92 {IM-33} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

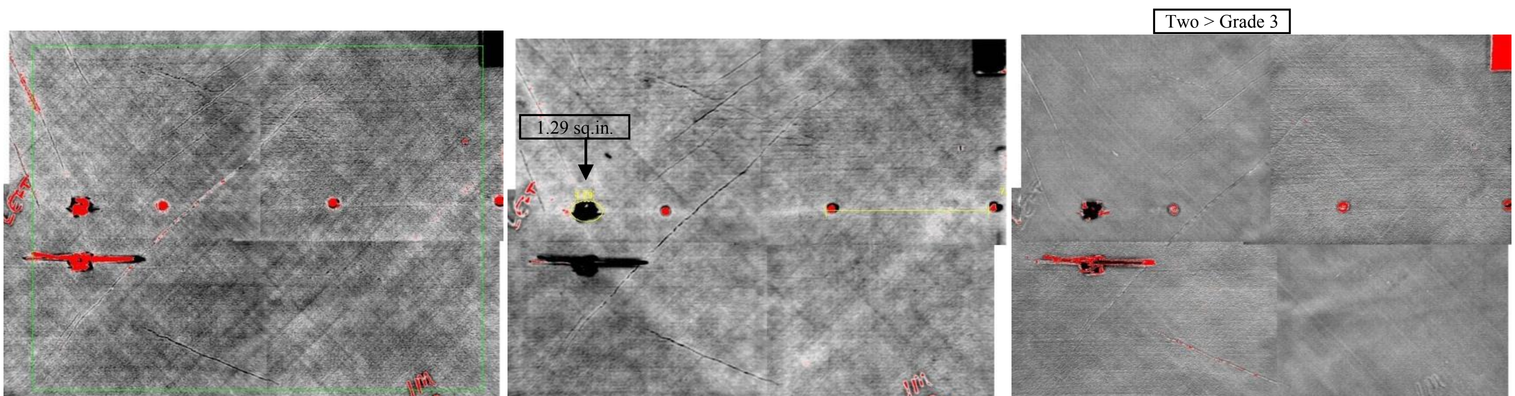


Figure 106. Post-Impact Thermography Panel 93 {IM-96} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.)

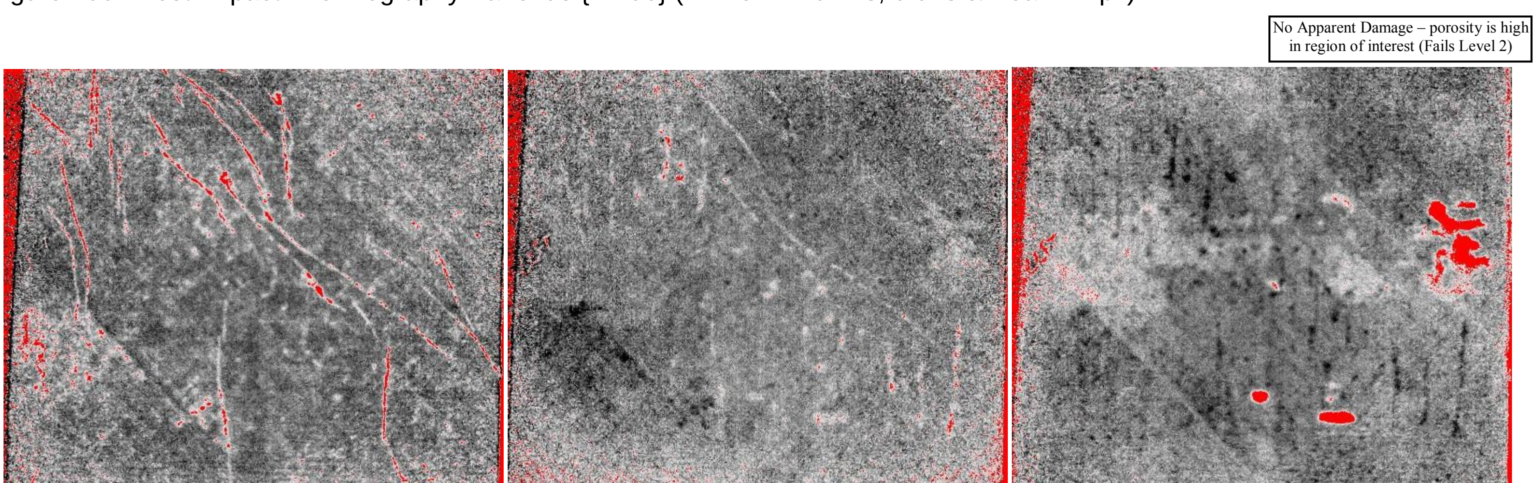


Figure 107. Post-Strike Thermography Back Panel 94 {LS-23} (1st Deriv. – 0.08s, 0.42s, 0.94s)

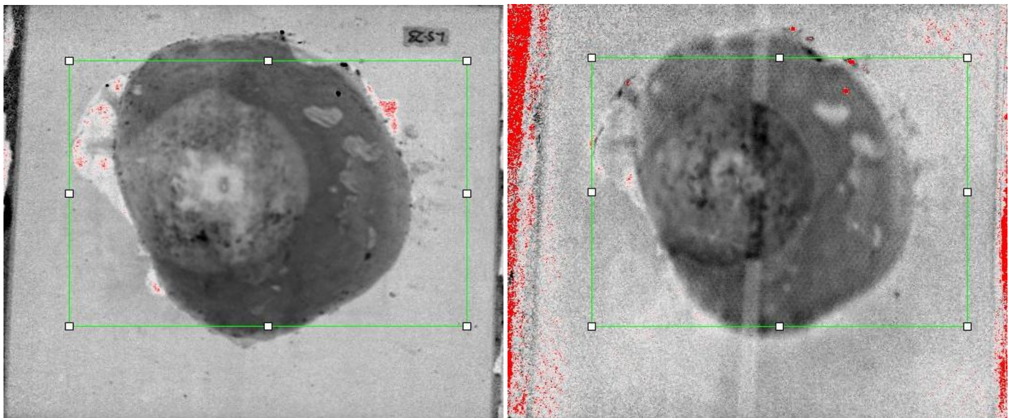


Figure 108. Post-Strike Thermography Front Panel 94 {LS-23} (1^{st} Deriv. – 0.4s & 8.66s)

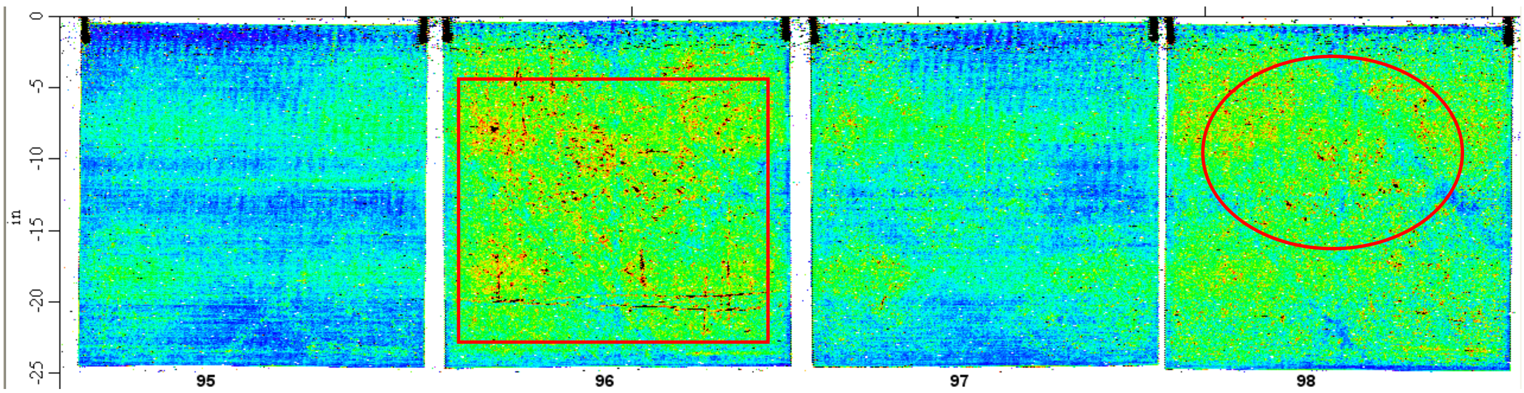


Figure 109. 5 MHz TTU Panel 95, 96, 97, 98

No Damage

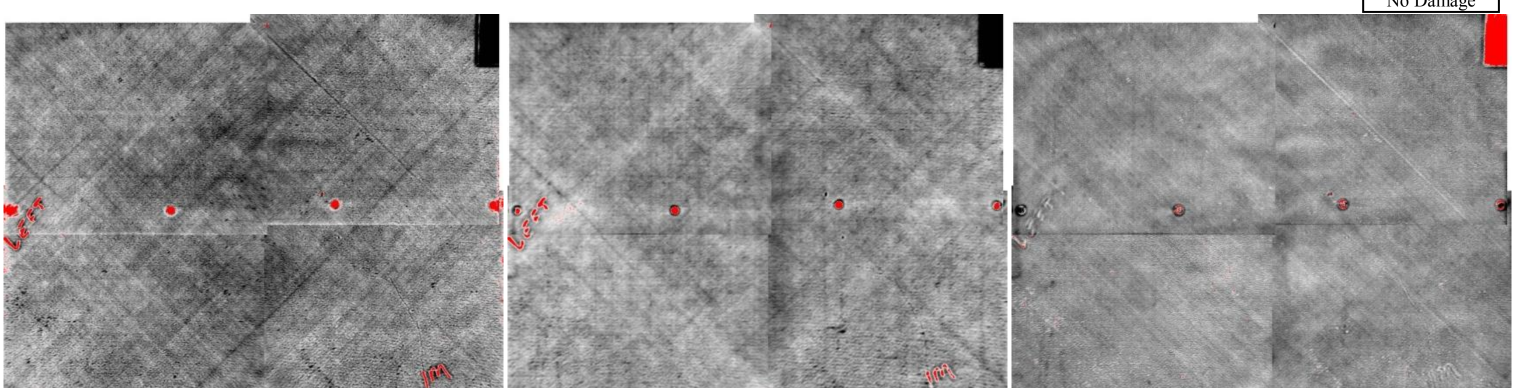


Figure 110. Post-Impact Thermography Panel 95 {IM-39} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

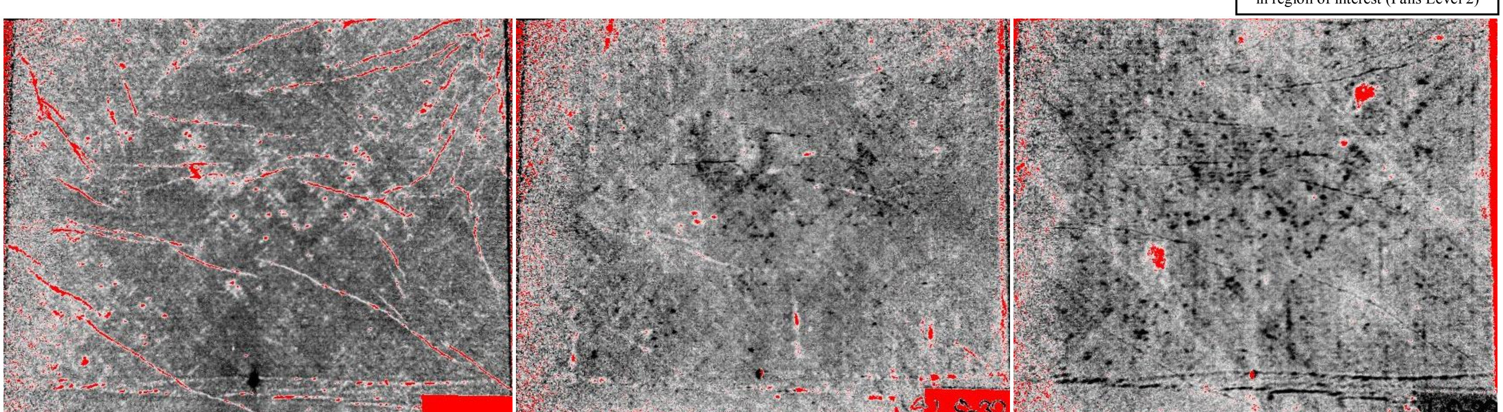


Figure 111. Post-Strike Thermography Back Panel 96 {LS-32} (1^{st} Deriv. – 0.08s, 0.42s, 0.94s)

Two > Grade 3

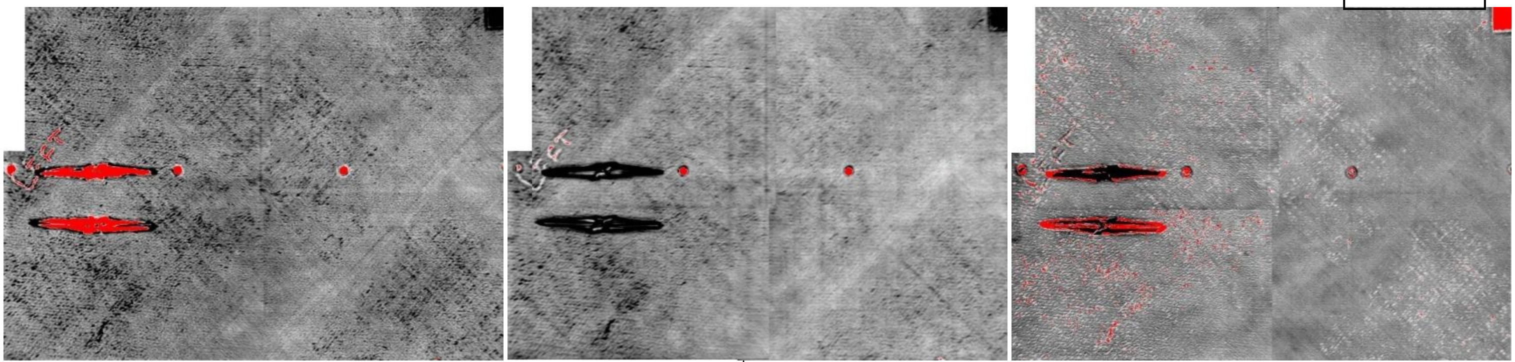


Figure 112. Post-Impact Thermography Panel 97 {IM-51} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

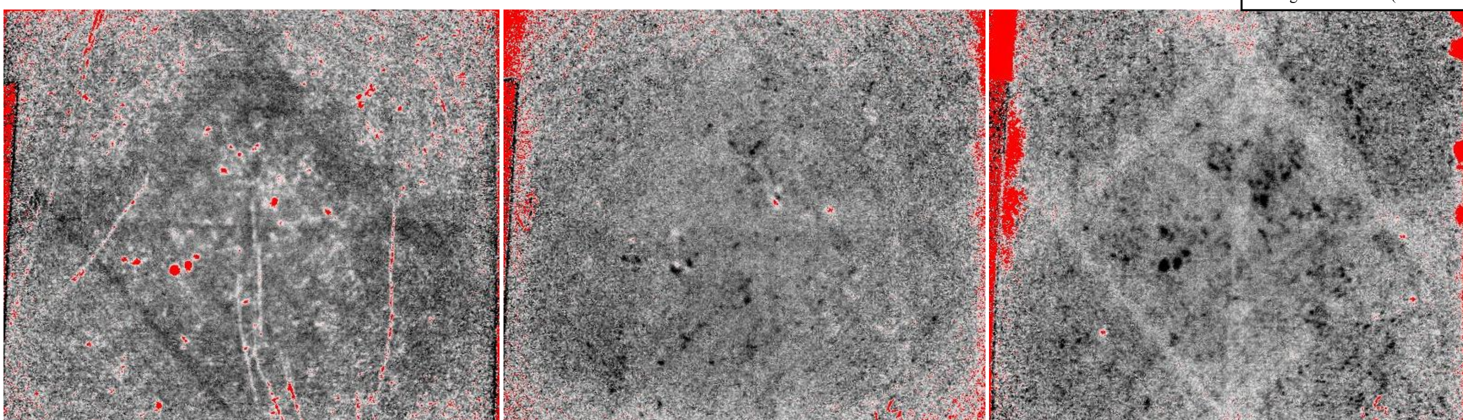


Figure 113. Post-Strike Thermography Back Panel 98 {LS-34} (1st Deriv. – 0.08s, 0.42s, 0.94s)

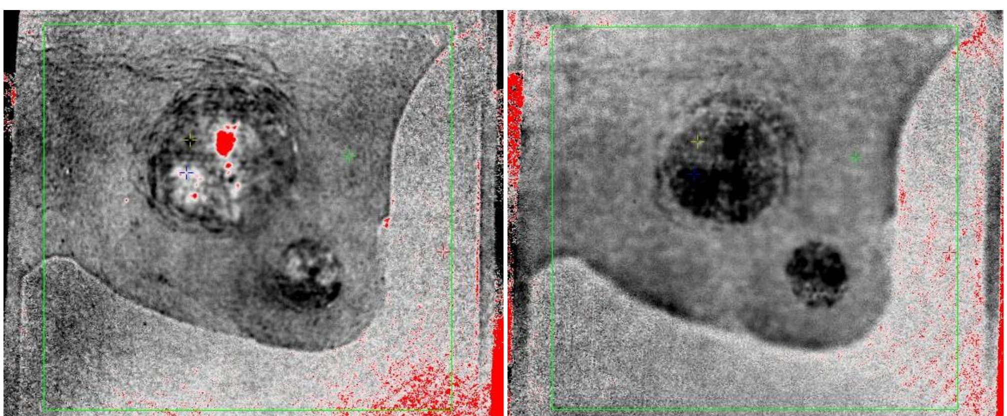


Figure 114. Post-Strike Thermography Front Panel 98 {LS-34} (1st Deriv. – 0.4s & 8.66s)

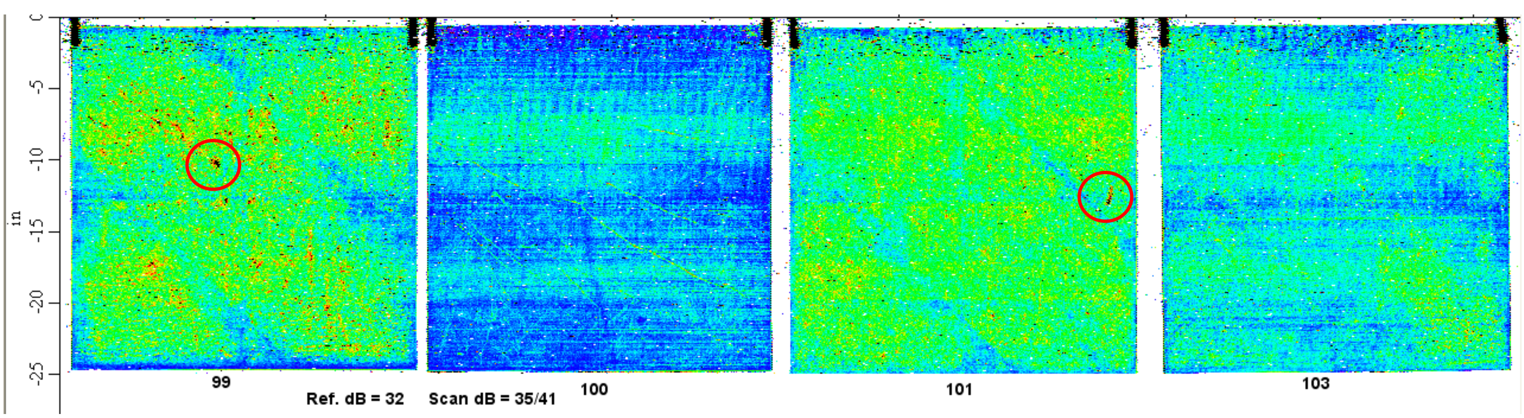


Figure 115. 5 MHz TTU Panel 99, 100, 101, 103

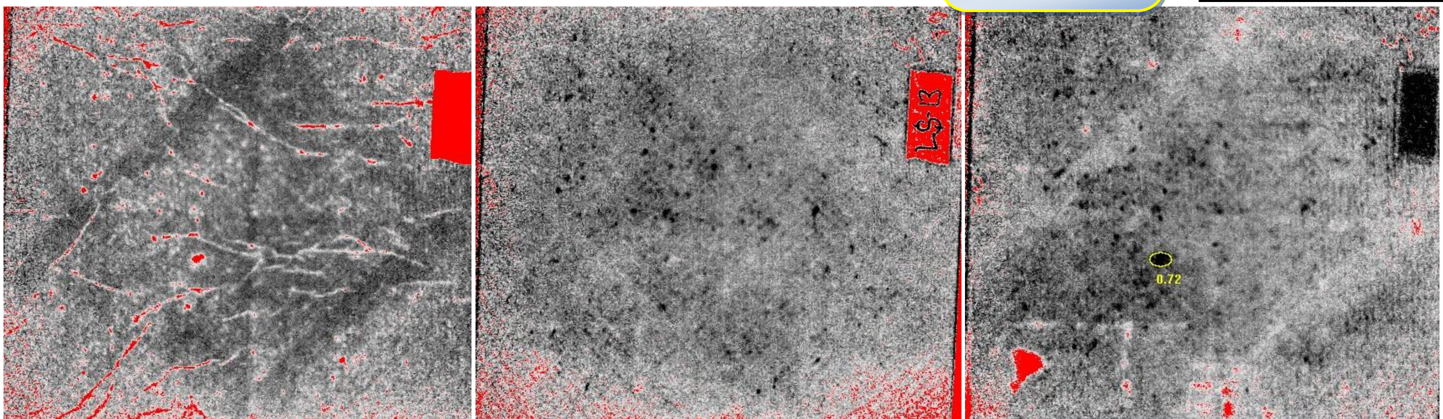


Figure 116. Post-Strike Thermography Back Panel 99 {LS-13} (1st Deriv. – 0.08s, 0.42s, 0.94s) <rotated 90° CCW>

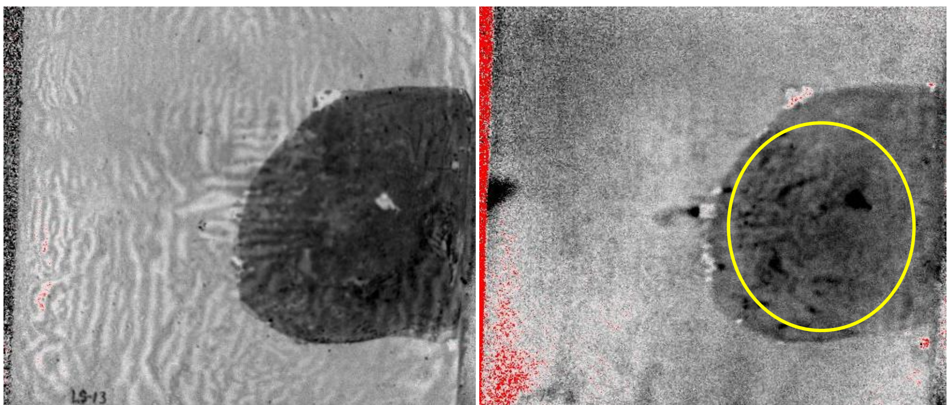


Figure 117. Post-Strike Thermography Front Panel 99 {LS-13} (1st Deriv. – 0.4s & 8.66s)

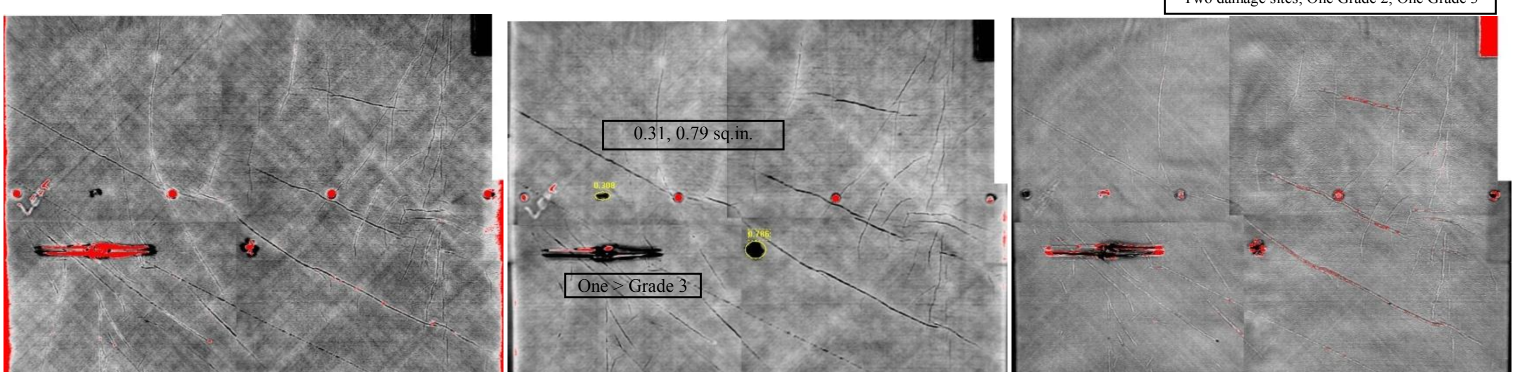


Figure 118. Post-Impact Thermography Panel 100 {IM-59} (1st Deriv. - 0.42, 0.94s & Peak Ampl)

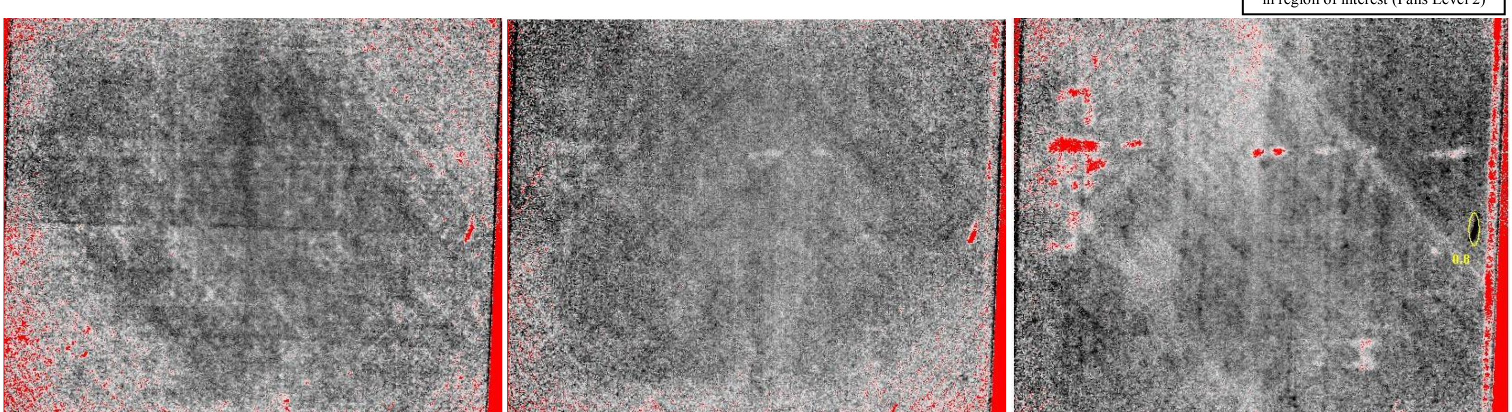


Figure 119. Post-Strike Thermography Back Panel 101 {LS-11} (1st Deriv. – 0.08s, 0.42s, 0.94s)

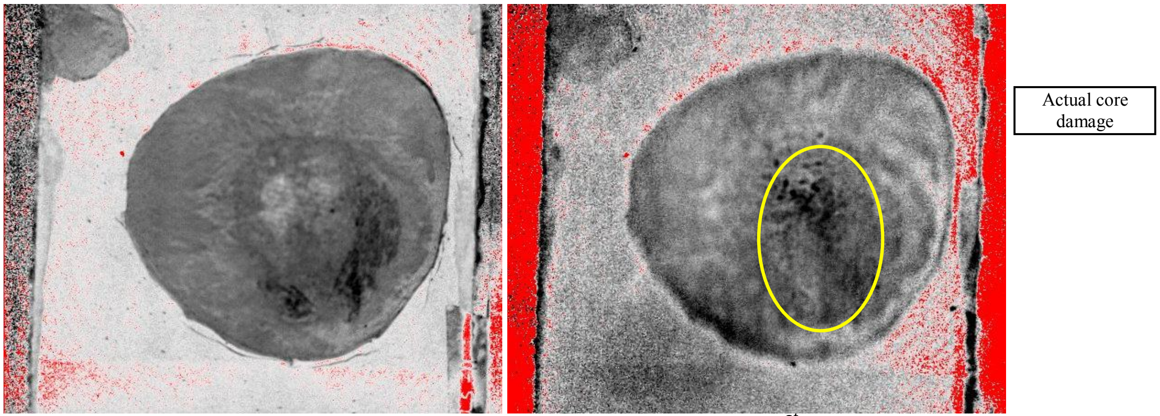


Figure 120. Post-Strike Thermography Front Panel 101 {LS-11} (1^{st} Deriv. – 0.4s & 8.66s)

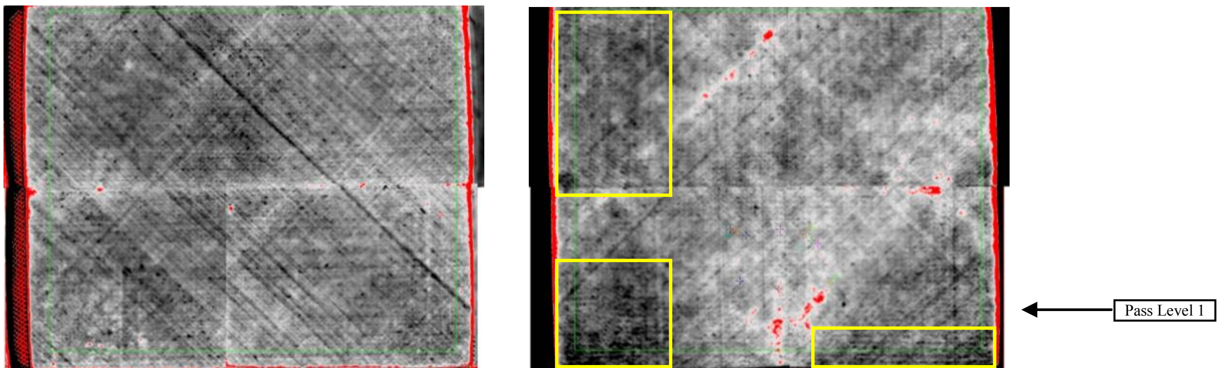


Figure 121. Thermography Panel 102 (1^{st} Deriv. - 0.42 & 0.94 sec)

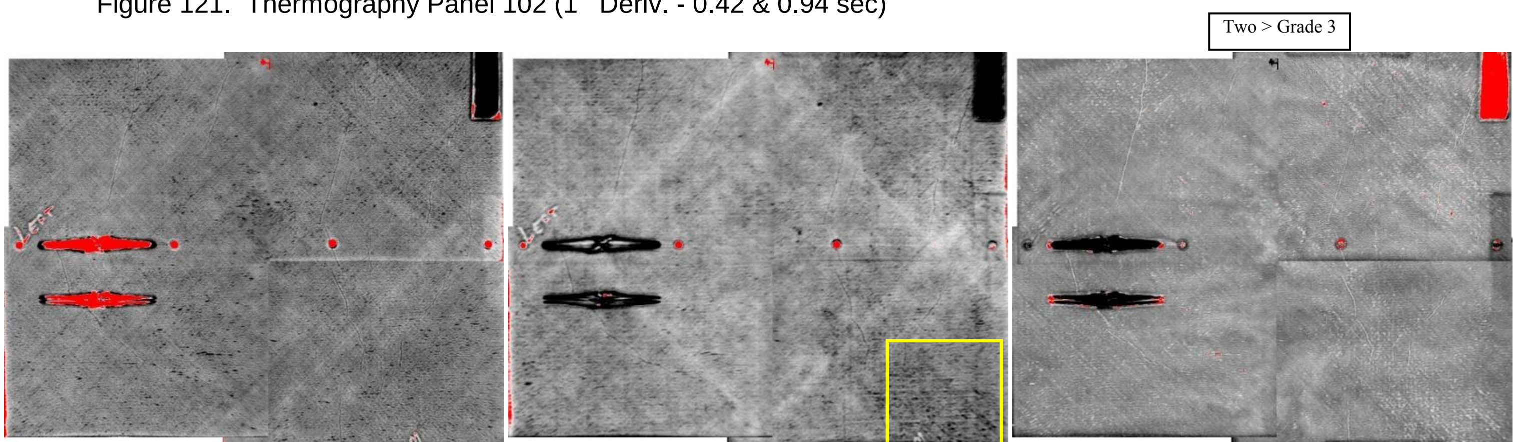


Figure 122. Post-Impact Thermography Panel 103 {IM-50} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

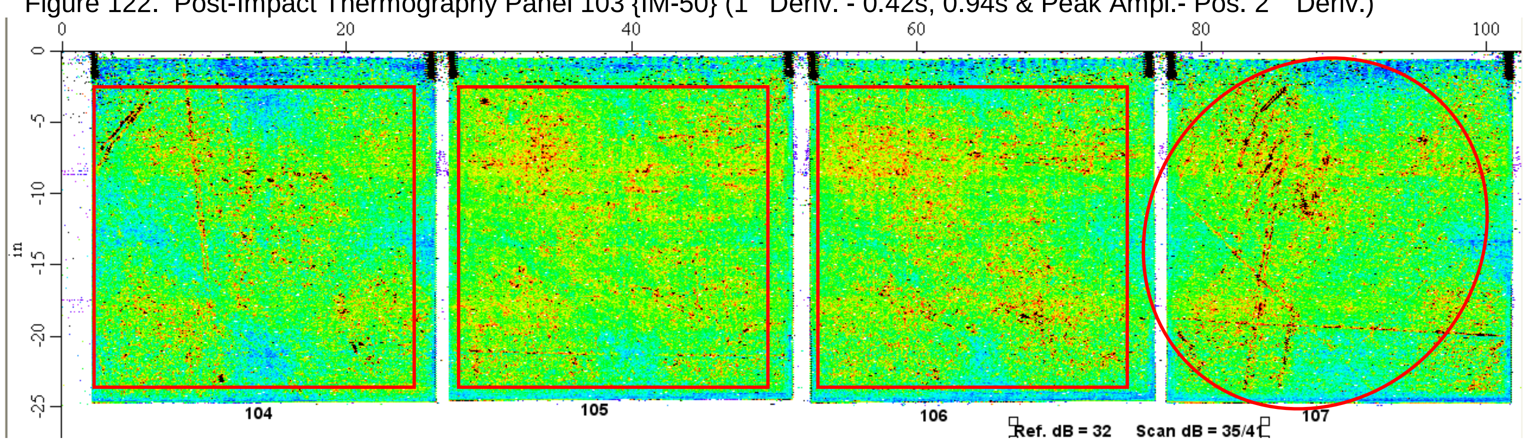


Figure 123. 5 MHz TTU Panel 104, 105, 106, 107

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

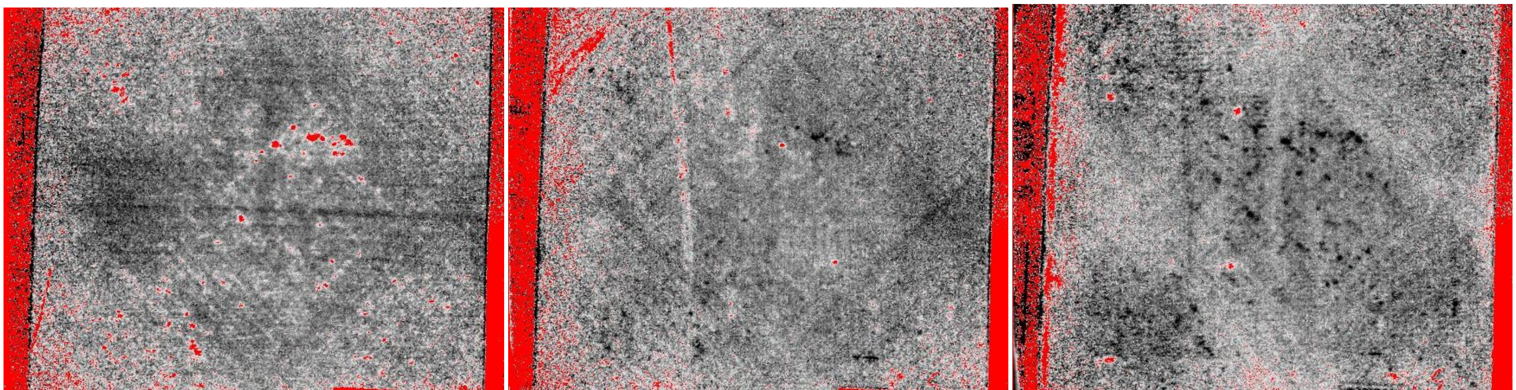
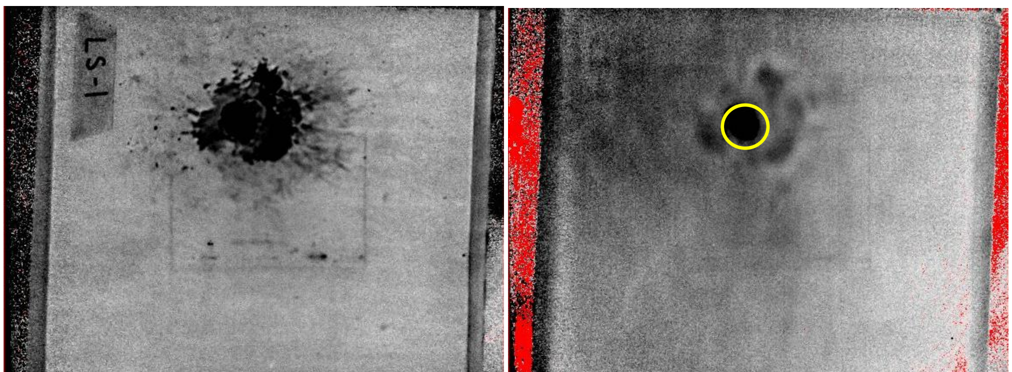


Figure 124. Post-Strike Thermography Back Panel 104 {LS-1} (1st Deriv. – 0.08s, 0.42s, 0.94s)



Actual core damage

Figure 125. Post-Strike Thermography Front Panel 104 {LS-1} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

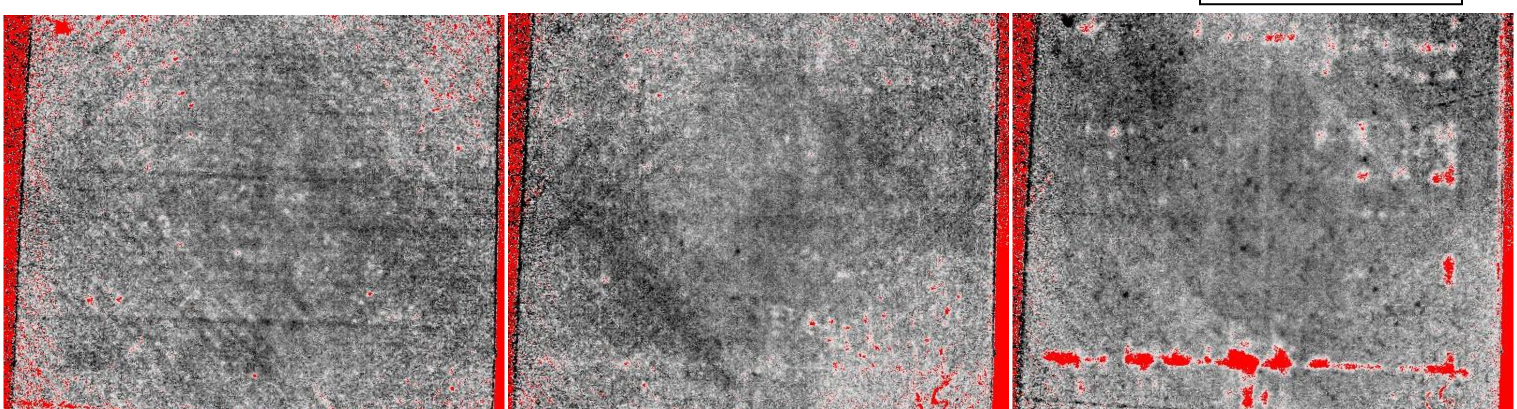


Figure 126. Post-Strike Thermography Back Panel 105 {LS-5} (1st Deriv. – 0.08s, 0.42s, 0.94s)

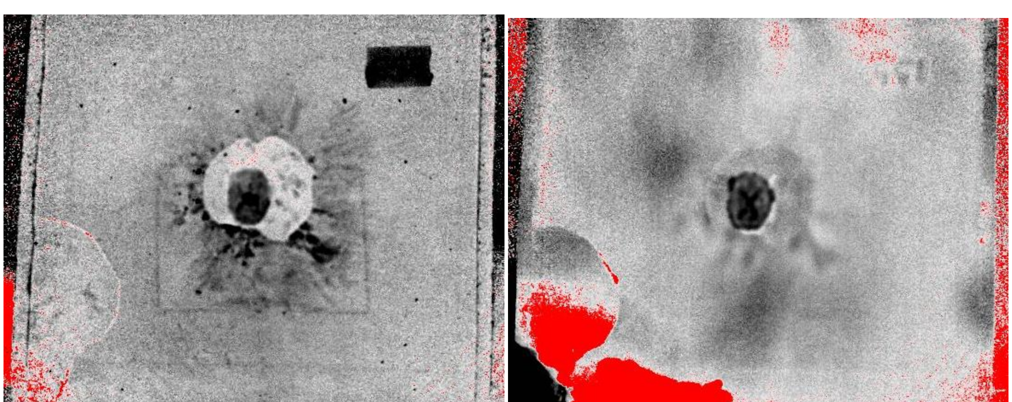


Figure 127. Post-Strike Thermography Front Panel 105 {LS-5} (1st Deriv. – 0.4s & 8.66s)

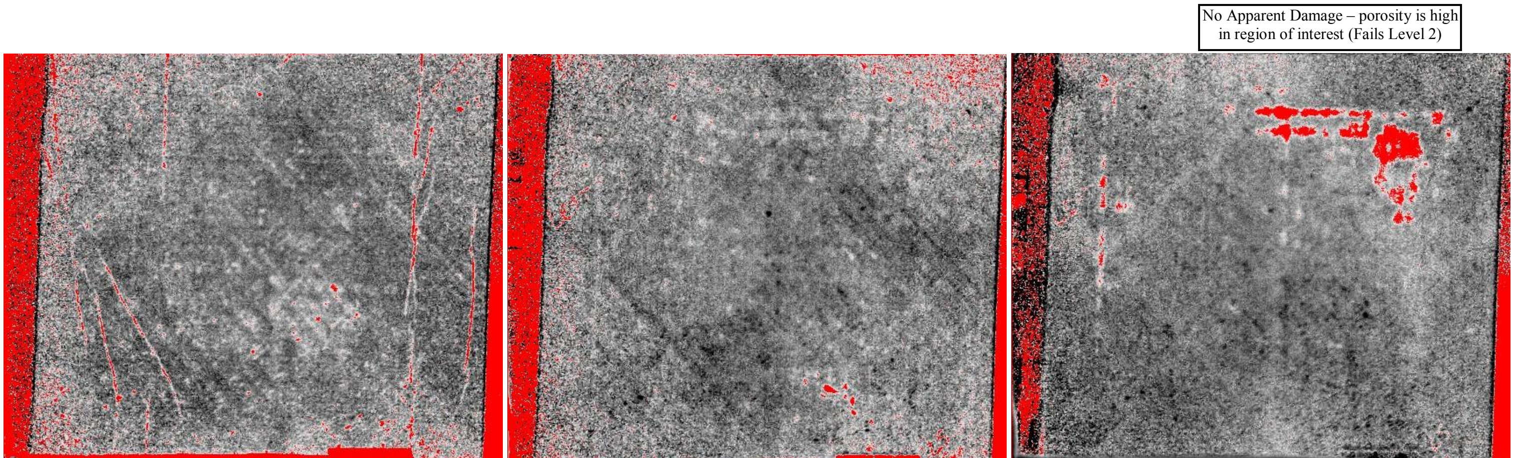


Figure 128. Post-Strike Thermography Back Panel 106 {LS-8} (1st Deriv. – 0.08s, 0.42s, 0.94s)

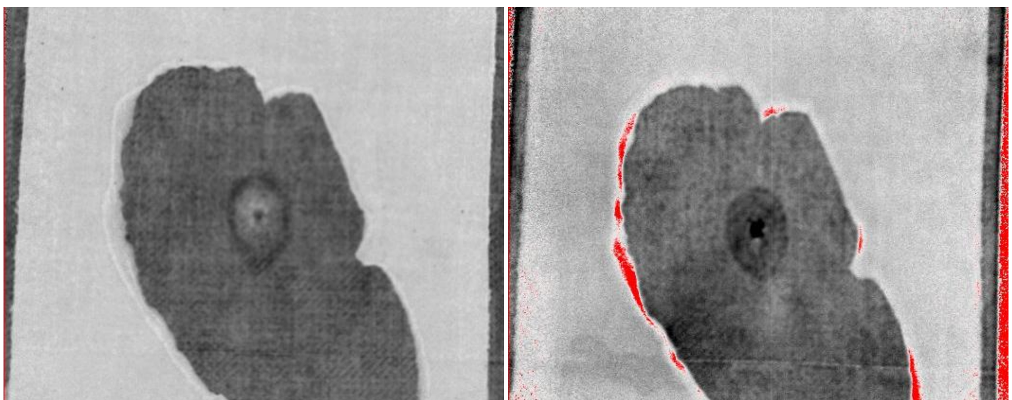


Figure 129. Post-Strike Thermography Front Panel 106 {LS-8} (1st Deriv. – 0.4s & 8.66s)

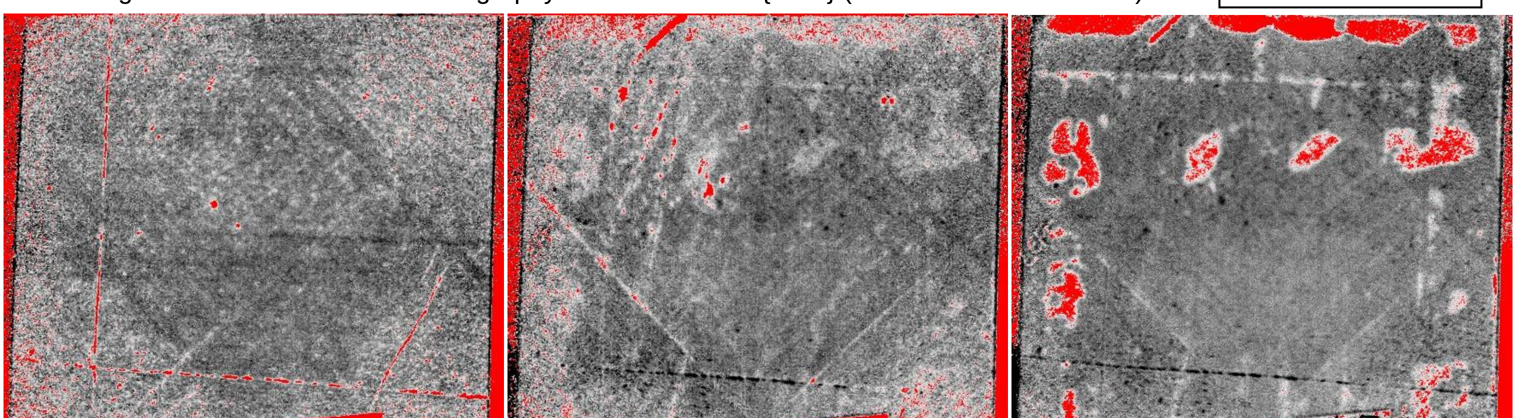


Figure 130. Post-Strike Thermography Back Panel 107 {LS-7} (1st Deriv. – 0.08s, 0.42s, 0.94s)

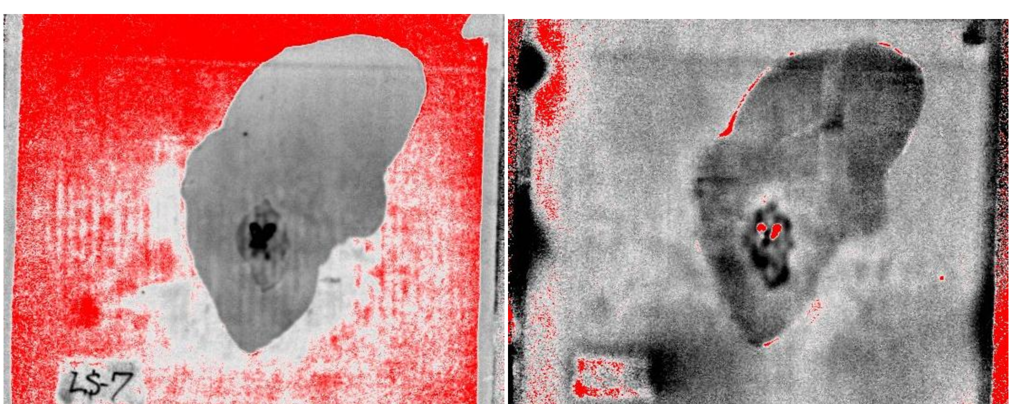


Figure 131. Post-Strike Thermography Front Panel 107 {LS-7} (1st Deriv. – 0.4s & 8.66s)

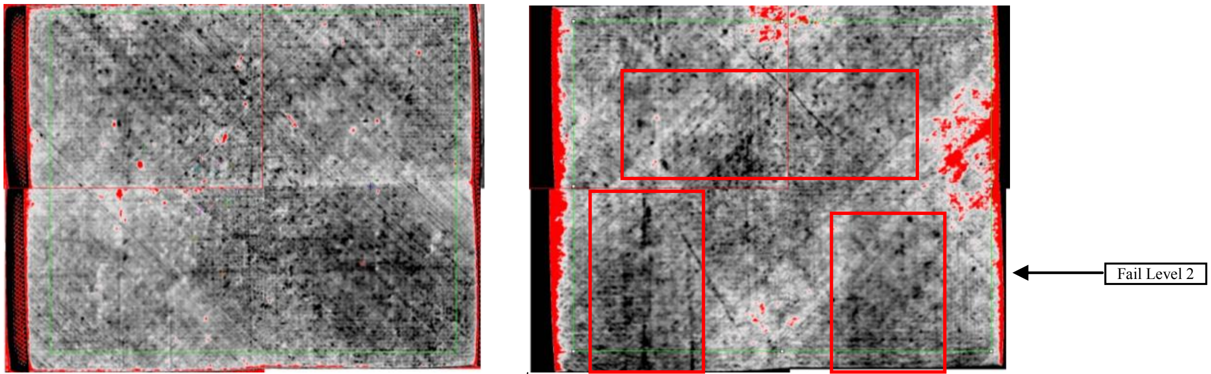


Figure 132. Thermography Panel AS108 (1^{st} Deriv. - 0.42 & 0.94 sec)

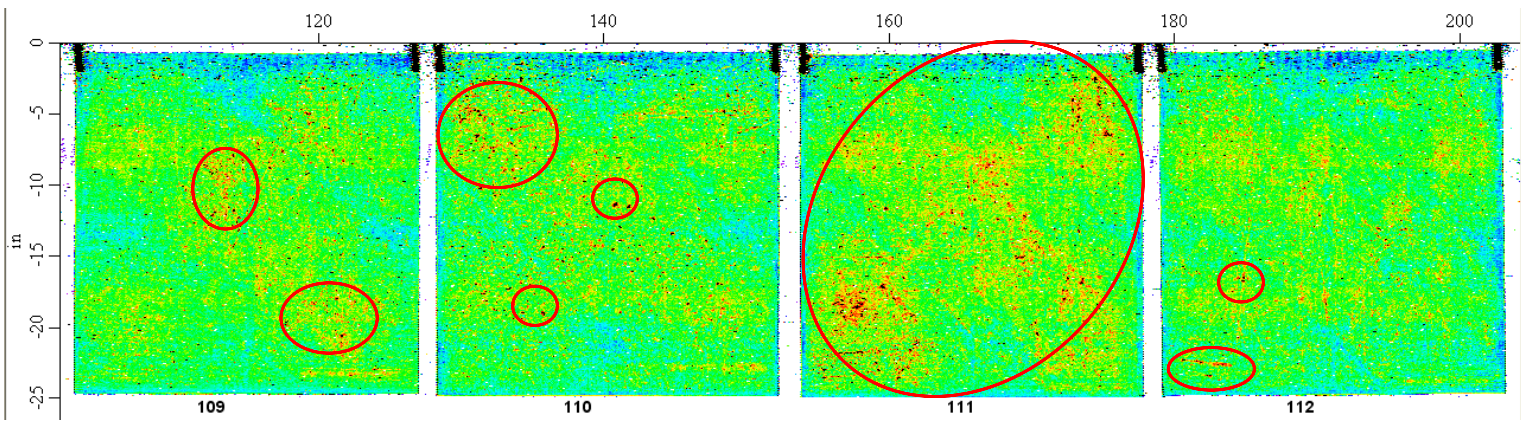


Figure 133. 5 MHz TTU Panel 109, 110, 111, 112

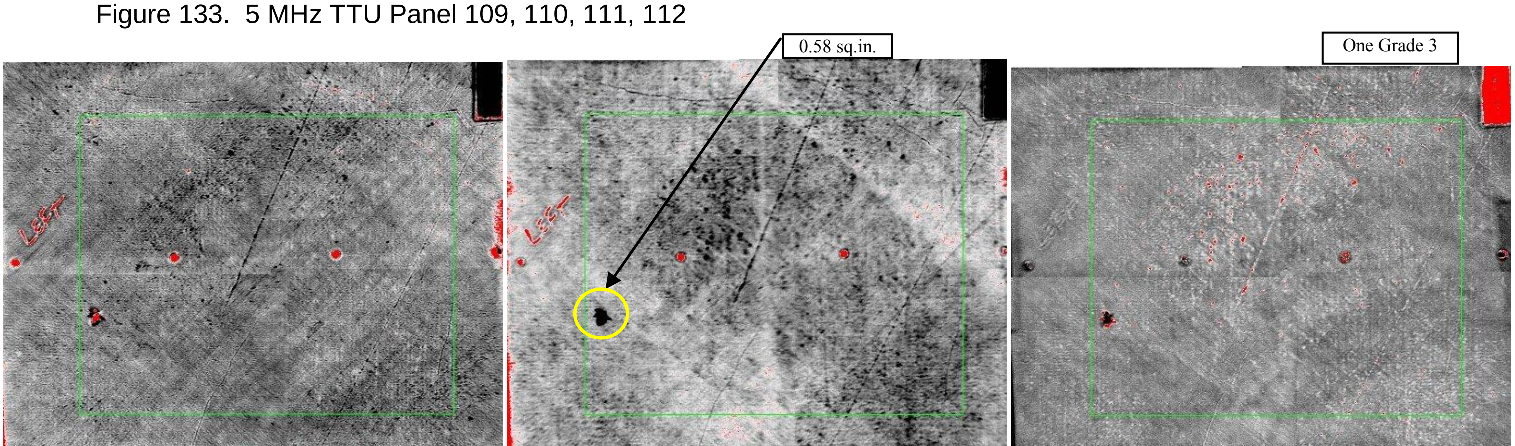


Figure 134. Post-Impact Thermography Panel 109 {IM-17} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.)

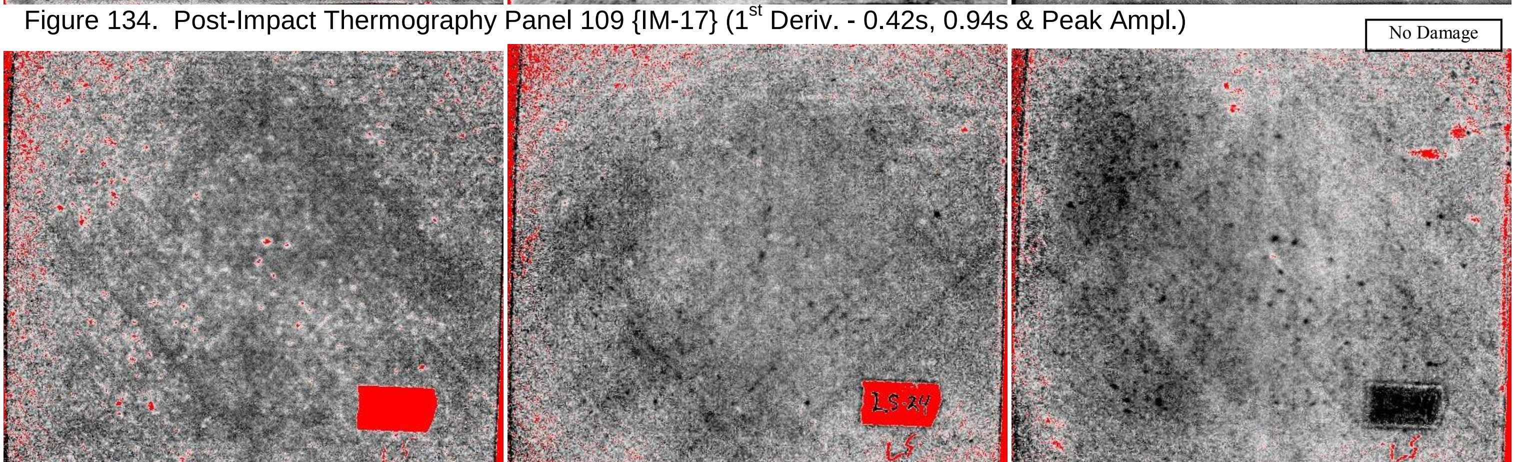


Figure 135. Post-Strike Thermography Back Panel 110 {LS-24} (1^{st} Deriv. – 0.08s, 0.42s, 0.94s)

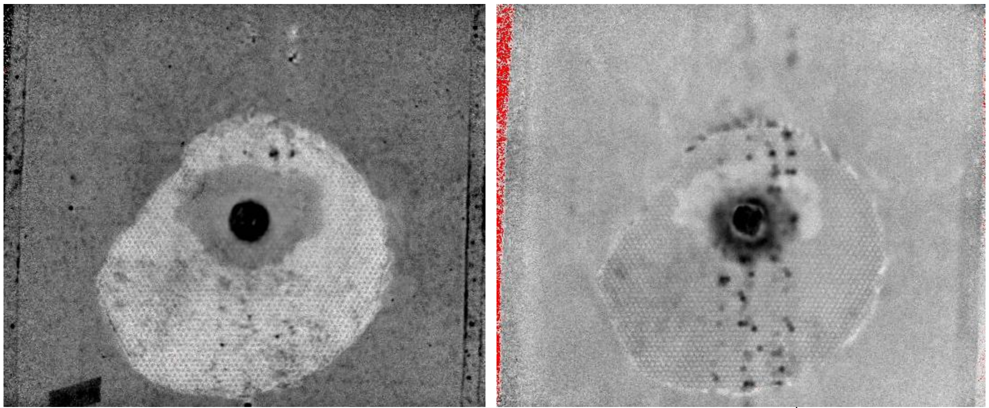


Figure 136. Post-Strike Thermography Front Panel 110 {LS-24} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

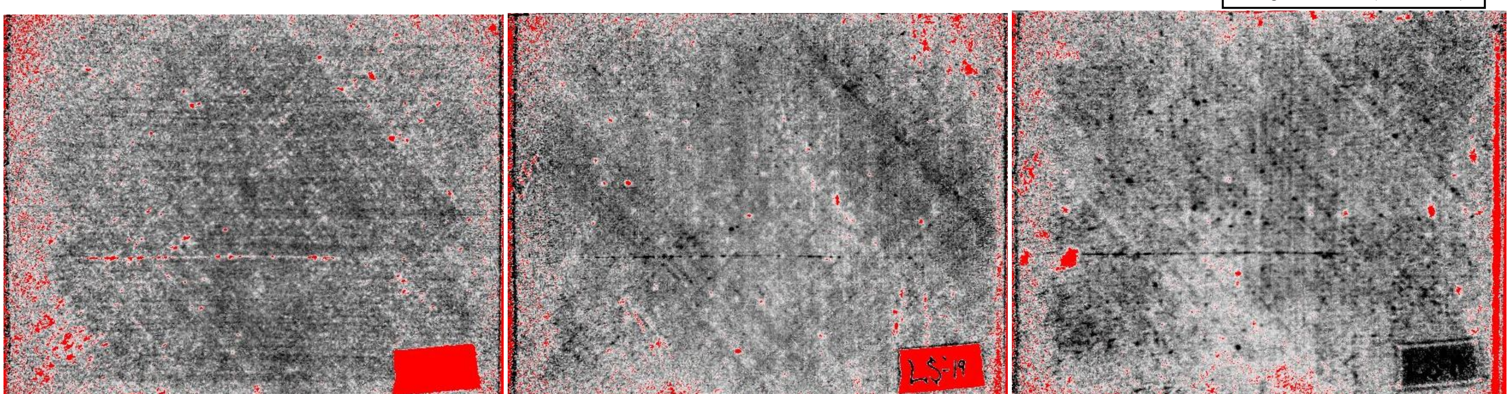


Figure 137. Post-Strike Thermography Back Panel 111 {LS-19} (1st Deriv. – 0.08s, 0.42s, 0.94s)

0.48 sq.in. Damage

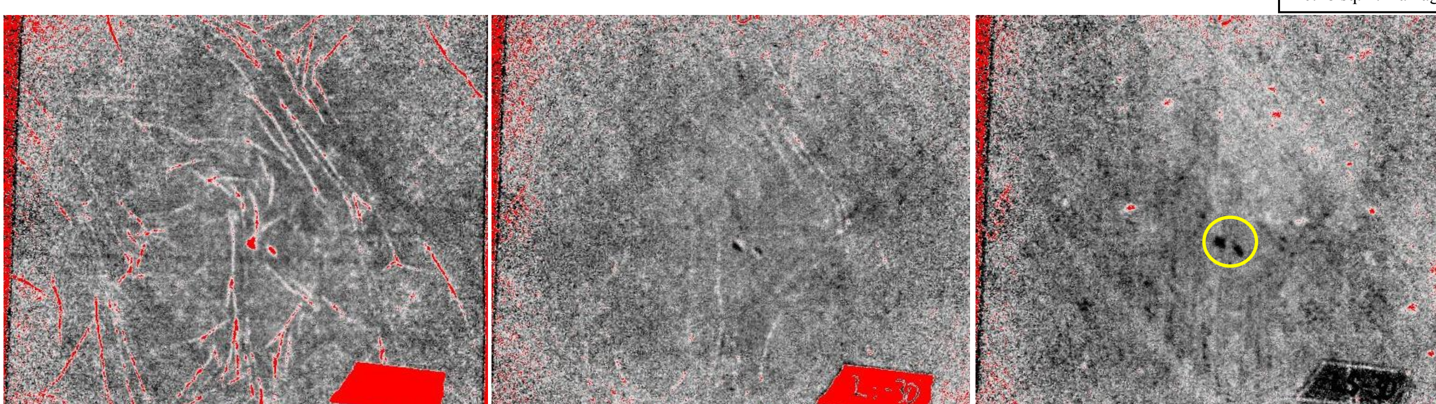


Figure 138. Post-Strike Thermography Back Panel 112 {LS-30} (1st Deriv. – 0.08s, 0.42s, 0.94s)

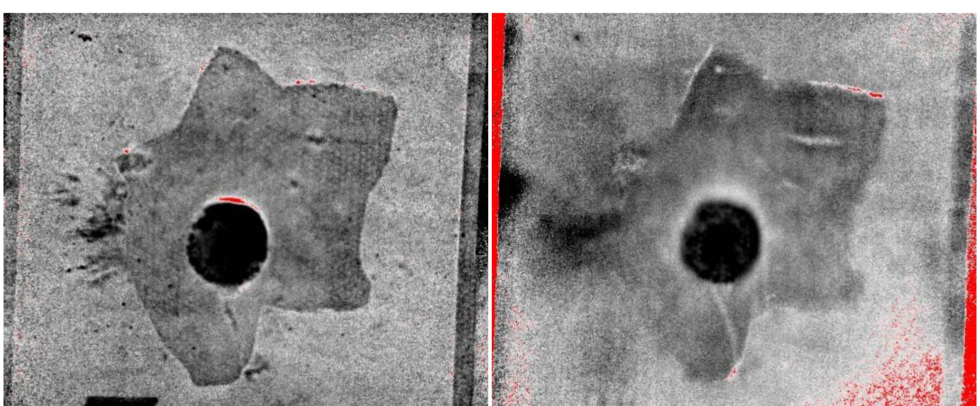


Figure 139. Post-Strike Thermography Front Panel 112 {LS-30} (1st Deriv. – 0.4s & 8.66s)

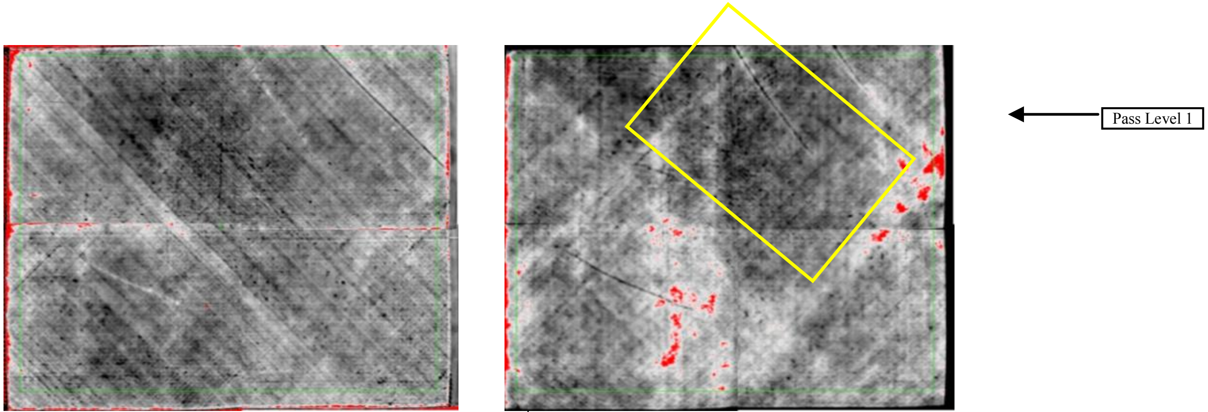


Figure 140. Thermography Panel AS113 (1st Deriv. - 0.42 & 0.94 sec)

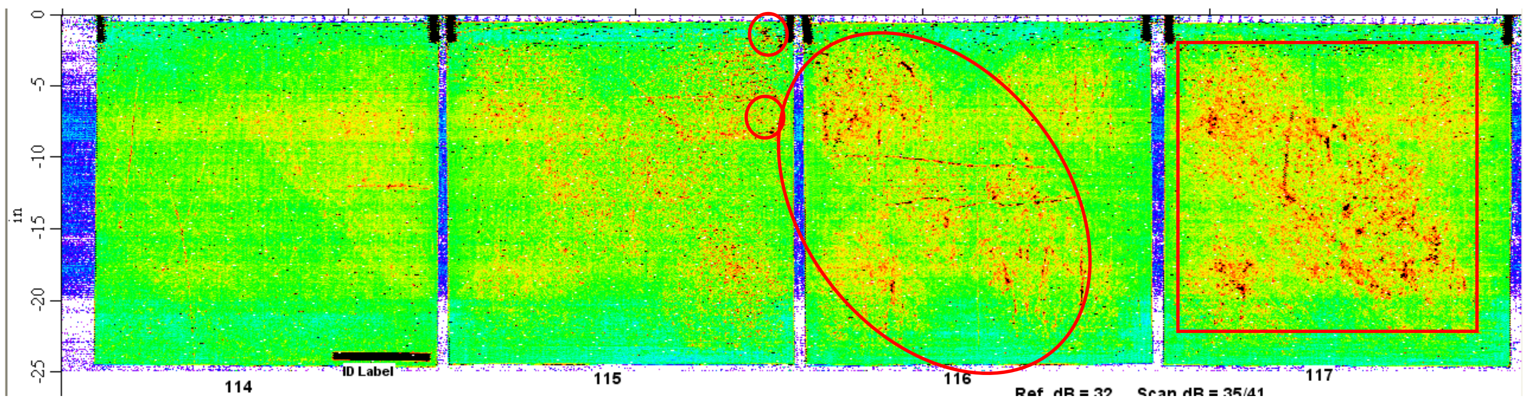


Figure 141. 5 MHz TTU Panel 114, 115, 116, 117

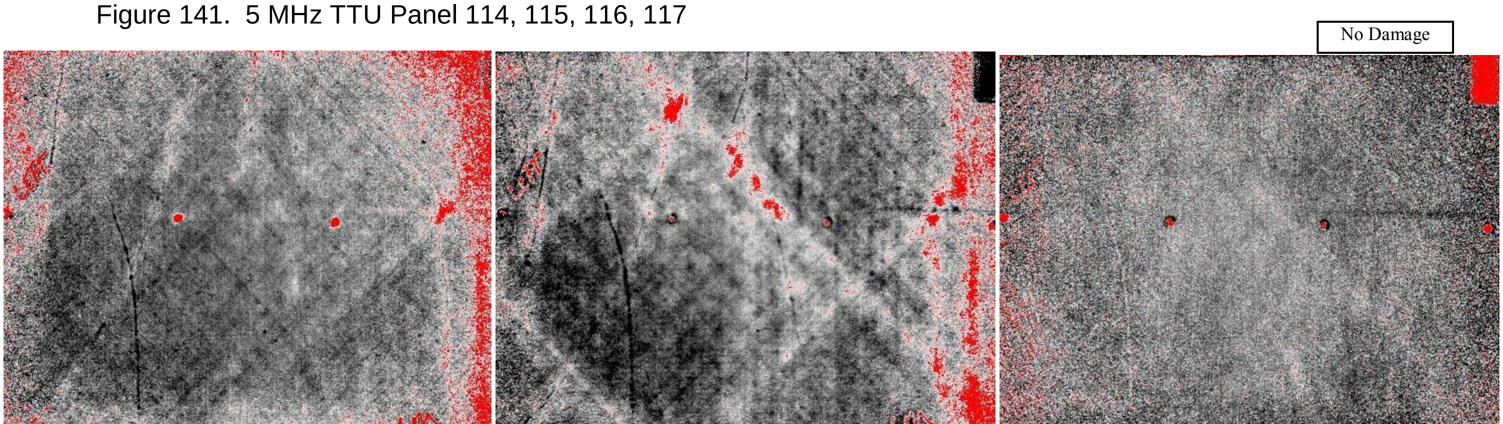


Figure 142. Post-Impact Thermography Panel 114 {IM-22} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.)

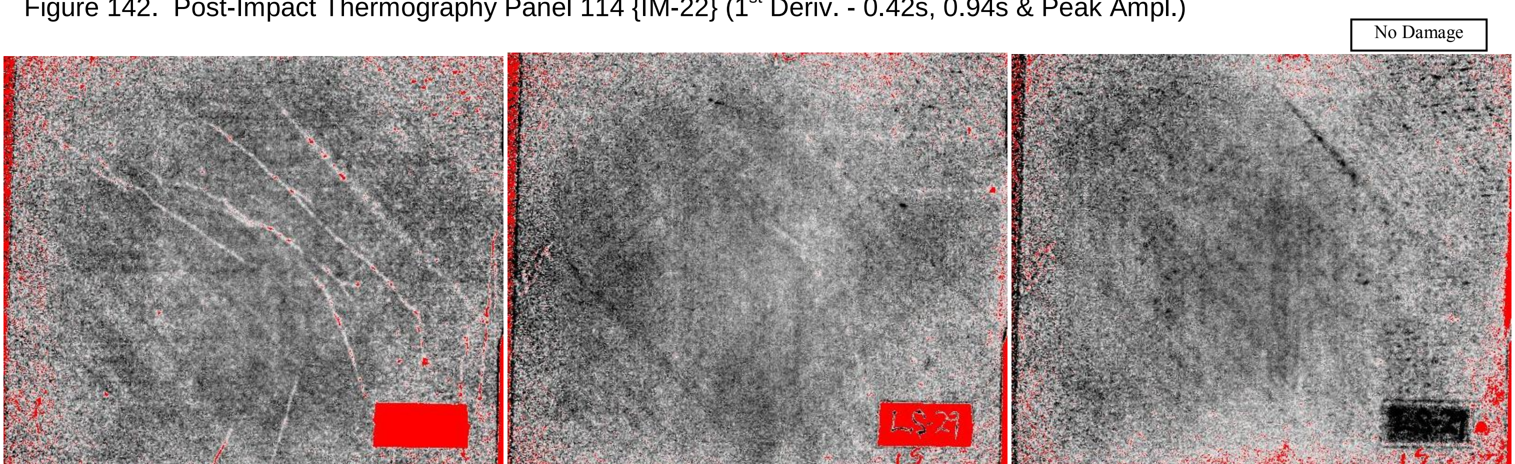


Figure 143. Post-Strike Thermography Back Panel 115 {LS-29} (1st Deriv. – 0.08s, 0.42s, 0.94s)

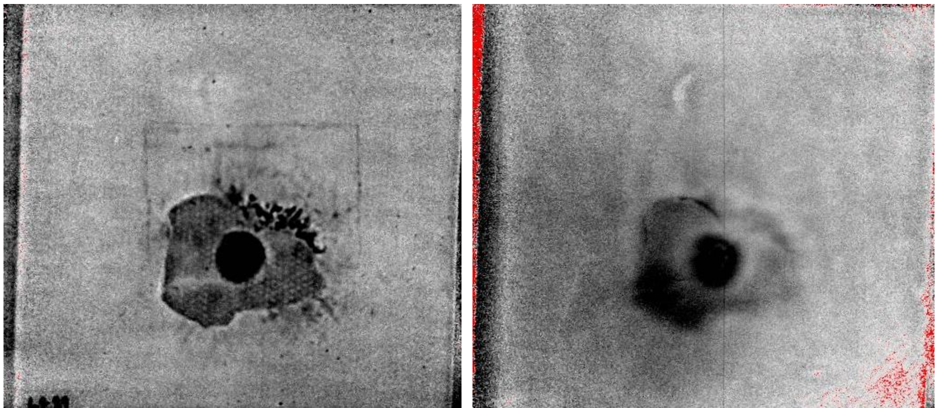


Figure 144. Post-Strike Thermography Front Panel 115 {LS-29} (1st Deriv. – 0.4s & 8.66s)

~2.2 sq.in. Damage

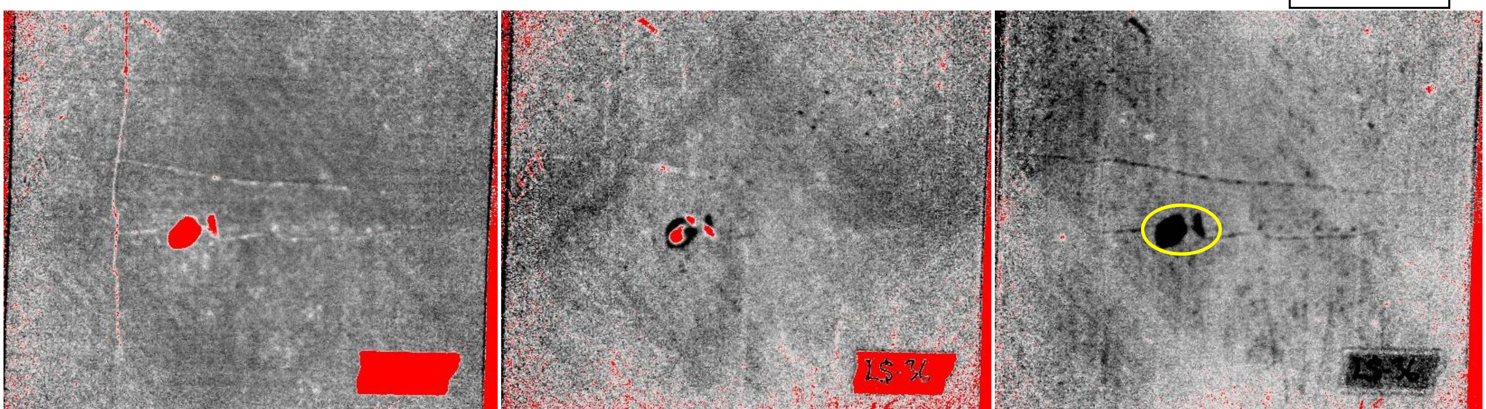


Figure 145. Post-Strike Thermography Back Panel 116 {LS-36} (1st Deriv. – 0.08s, 0.42s, 0.94s)

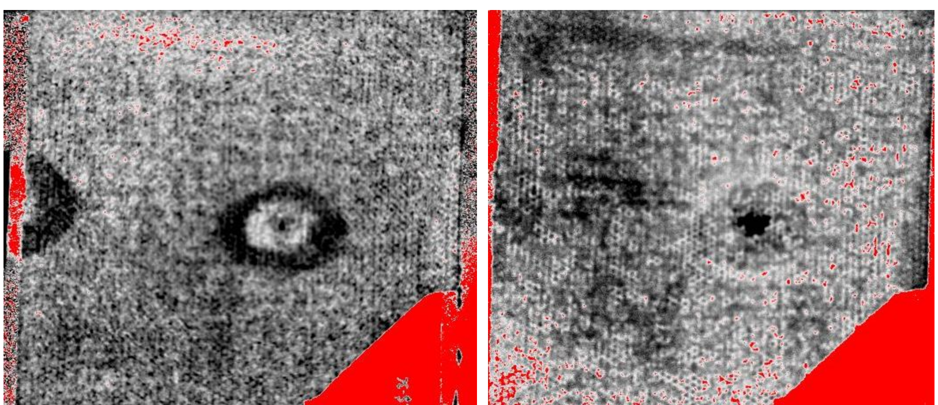


Figure 146. Post-Strike Thermography Front Panel 116 {LS-36} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

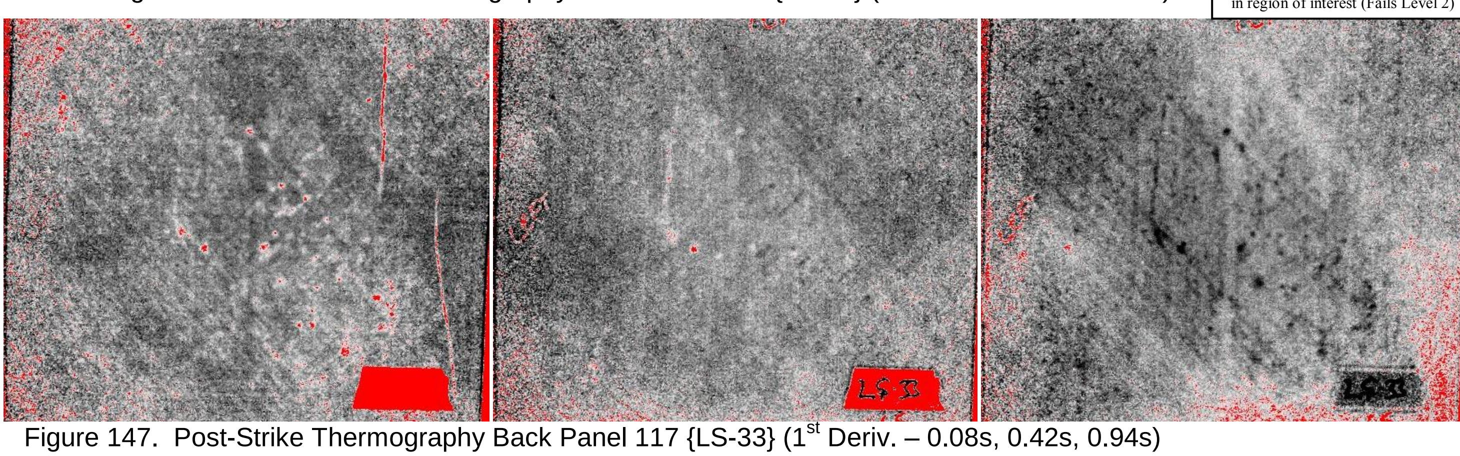


Figure 147. Post-Strike Thermography Back Panel 117 {LS-33} (1st Deriv. – 0.08s, 0.42s, 0.94s)

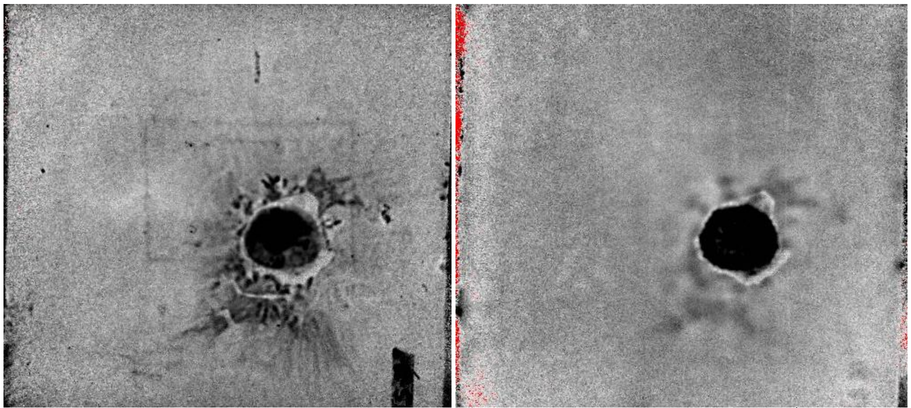


Figure 148. Post-Strike Thermography Front Panel 117 {LS-33} (1st Deriv. – 0.4s & 8.66s)

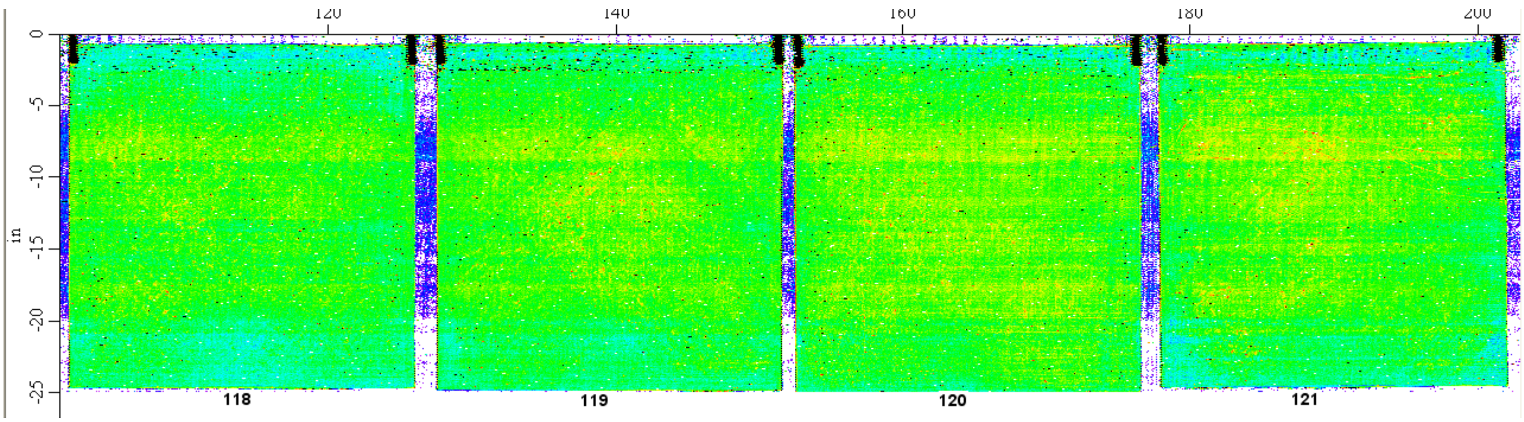


Figure 149. 5 MHz TTU Panel 118, 119, 120, 121

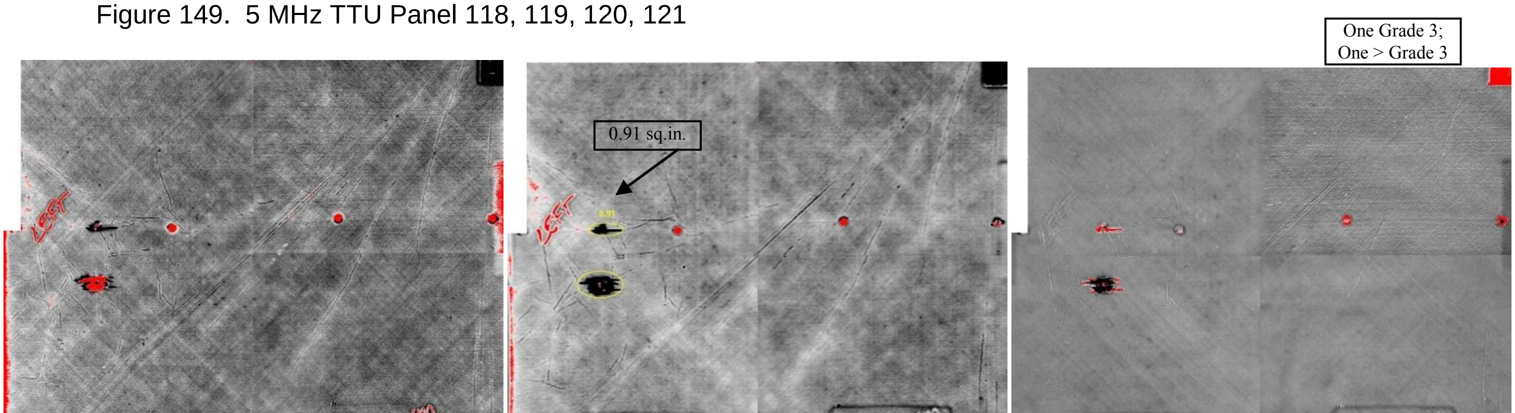


Figure 150. Post-Impact Thermography Panel 118 {IM-3} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.)

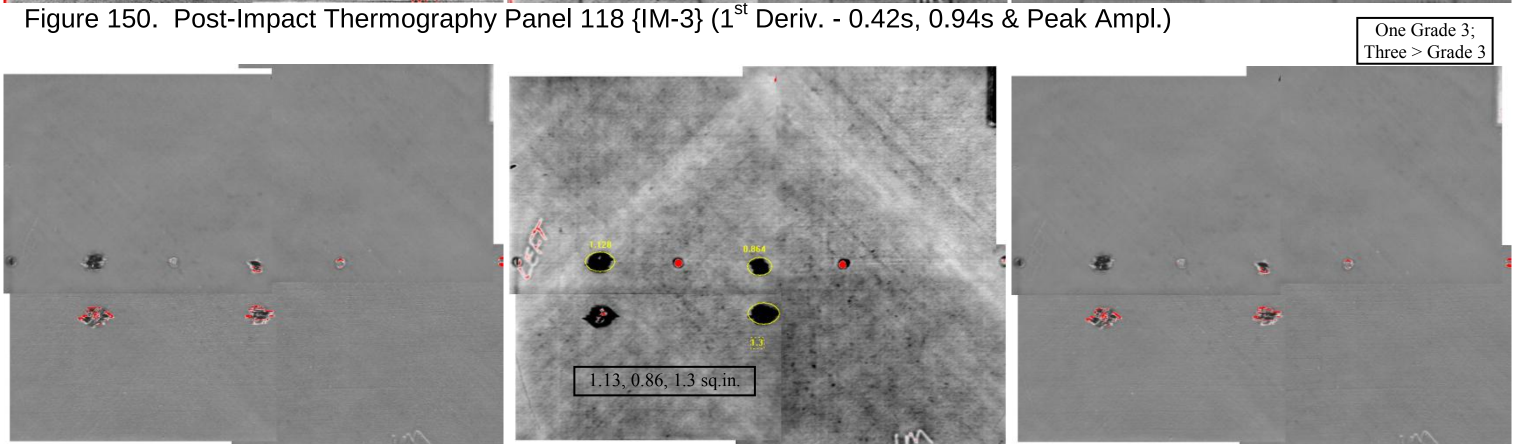


Figure 151. Post-Impact Thermography Panel 119 {IM-97} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

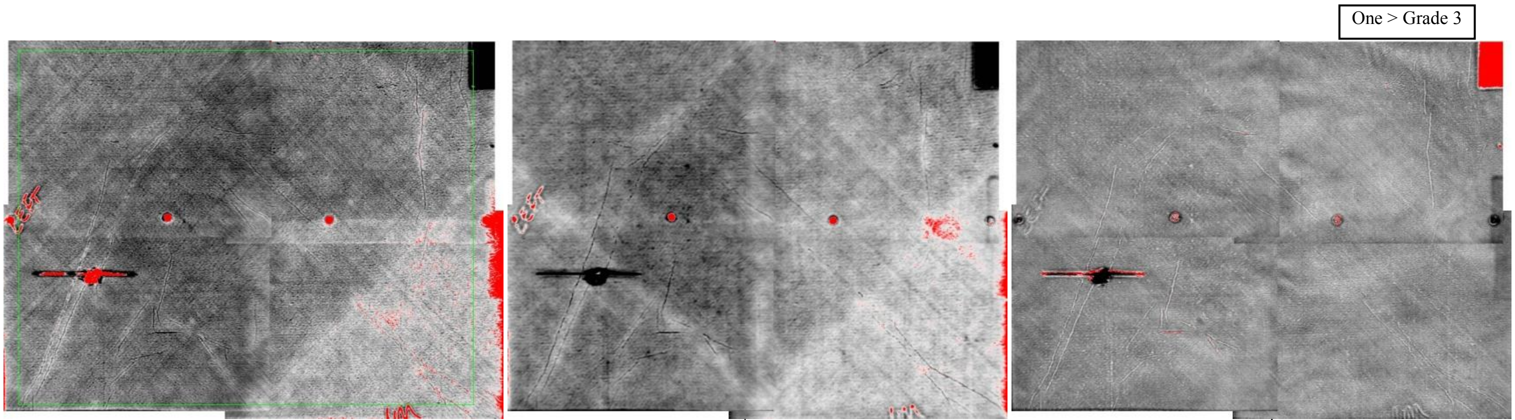


Figure 152. Post-Impact Thermography Panel 120 {IM-6} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

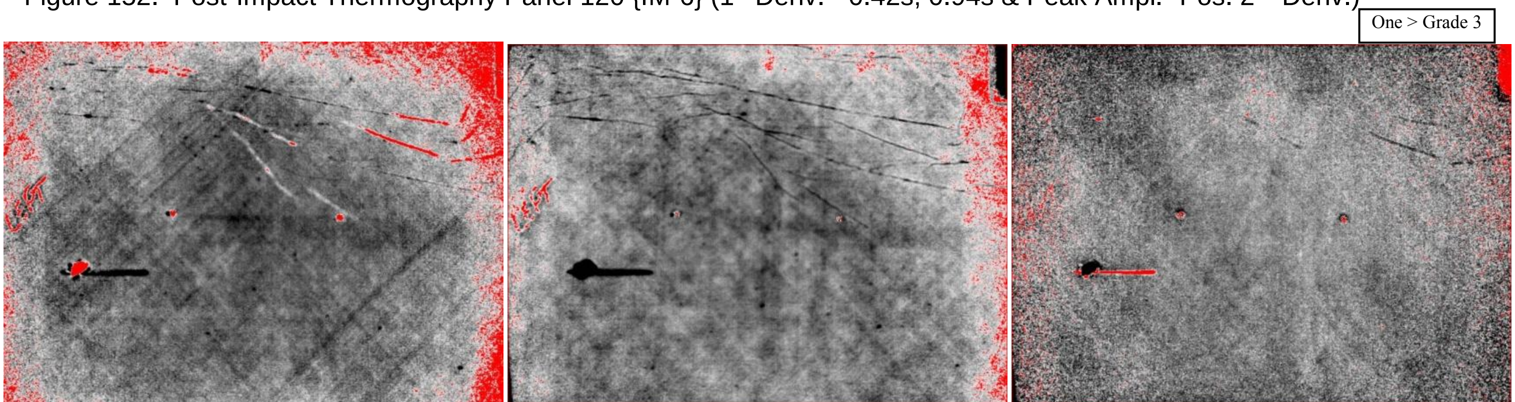


Figure 153. Post-Impact Thermography Panel 121 {IM-8} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

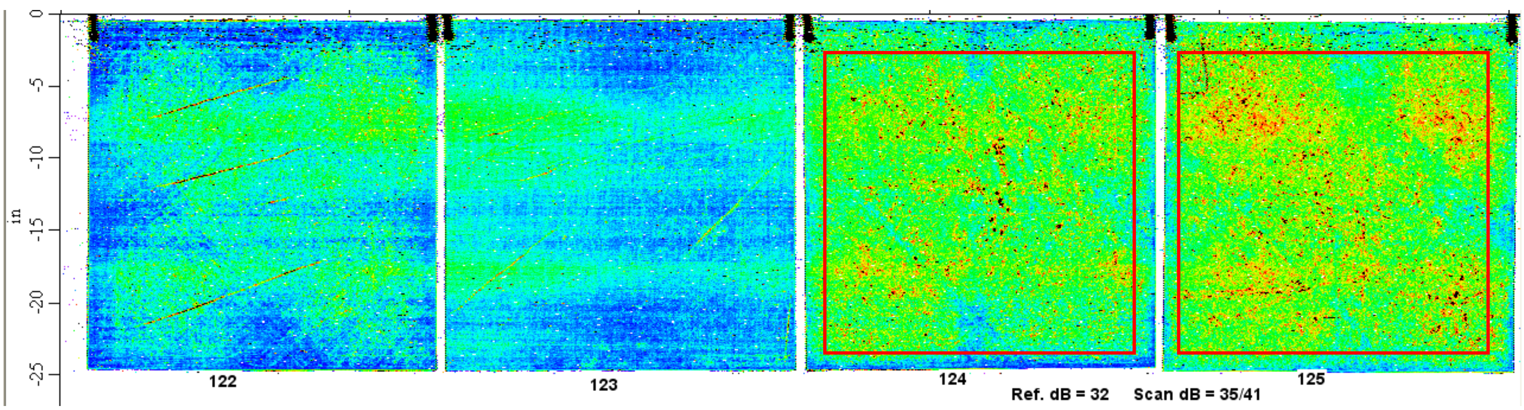


Figure 154. 5 MHz TTU Panel 122, 123, 124, 125

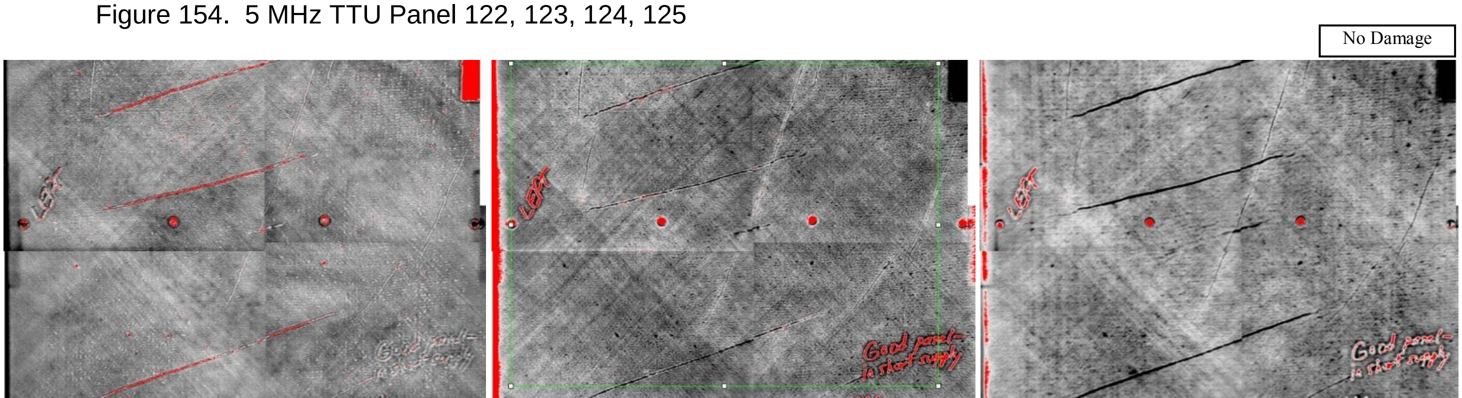


Figure 155. Post-Impact Thermography Panel 122 {IM-10} (1^{st} Deriv. - 0.42, 0.94s & Peak Ampl.)

No Damage

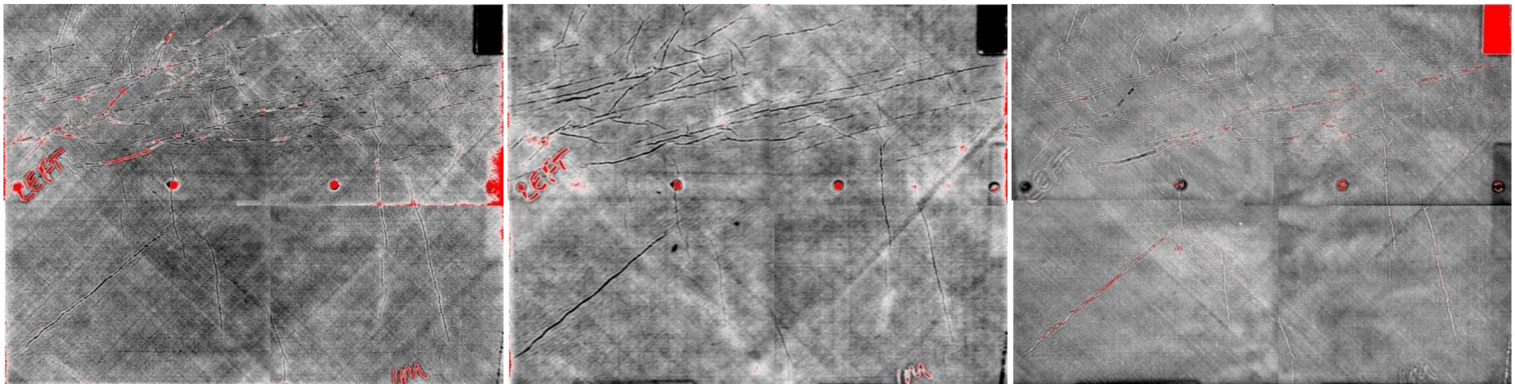


Figure 156. Post-Impact Thermography Panel 123 {IM-13} (1st Deriv. - 0.42, 0.94s & Peak Ampl)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

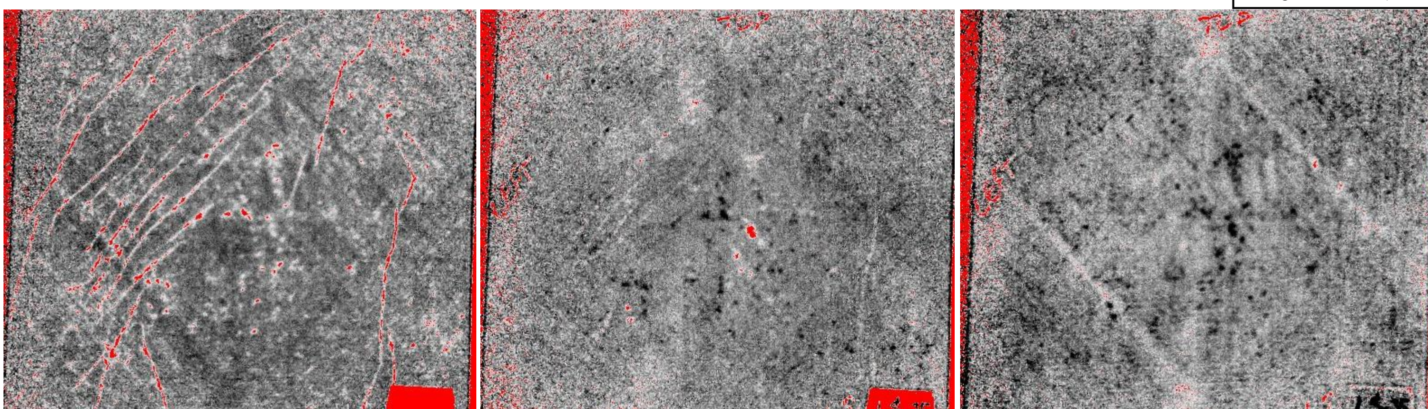


Figure 157. Post-Strike Thermography Back Panel 124 {LS-35} (1st Deriv. – 0.08s, 0.42s, 0.94s)

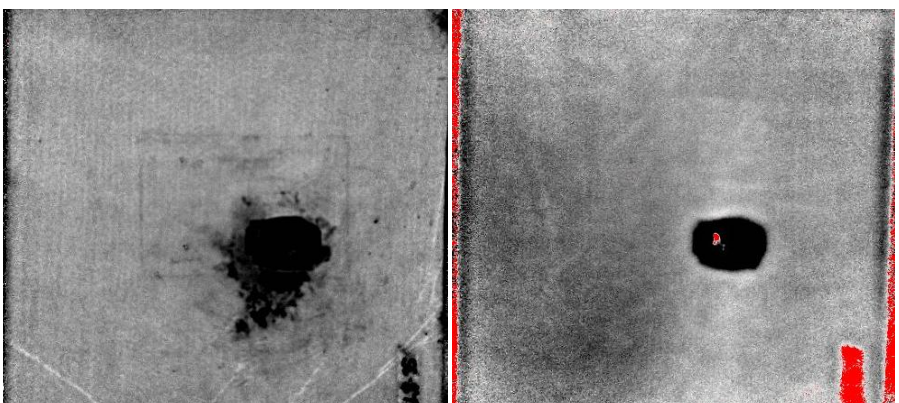


Figure 158. Post-Strike Thermography Front Panel 124 {LS-35} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

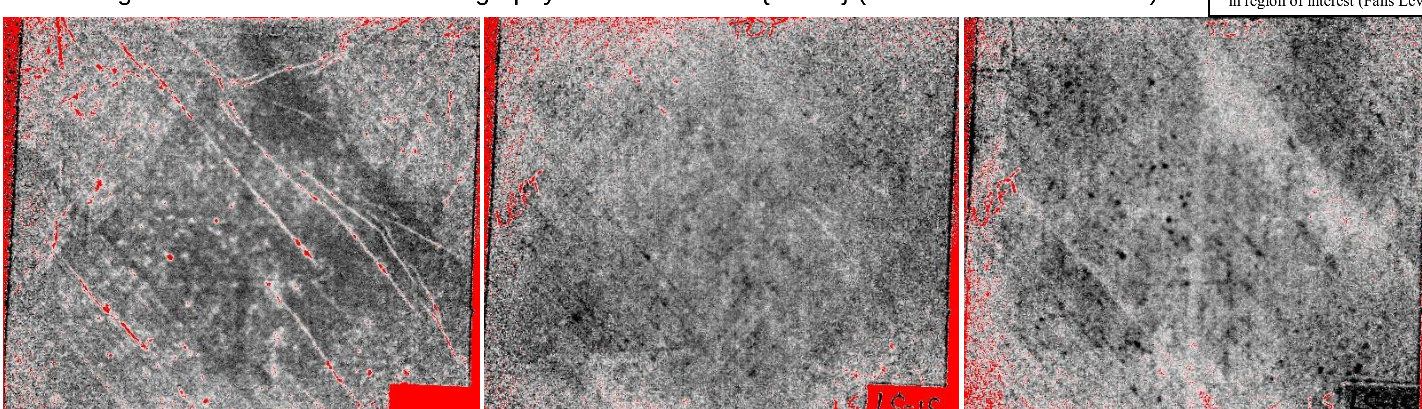


Figure 159. Post-Strike Thermography Back Panel 125 {LS-15} (1st Deriv. – 0.08s, 0.42s, 0.94s)

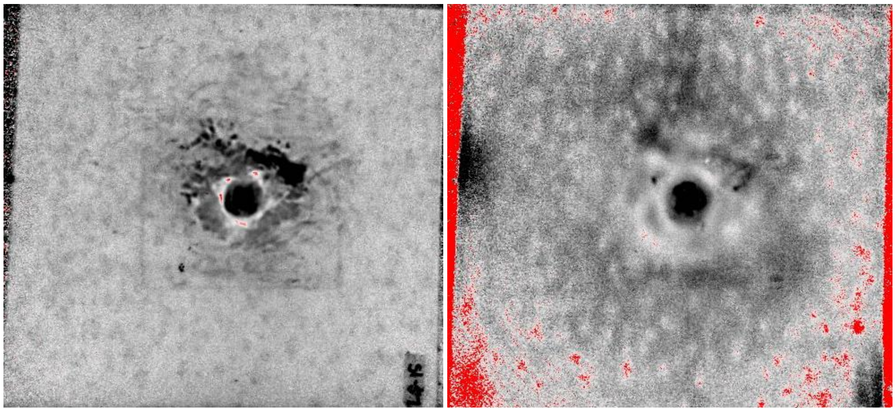


Figure 160. Post-Strike Thermography Front Panel 125 {LS-15} (1st Deriv. – 0.4s & 8.66s)

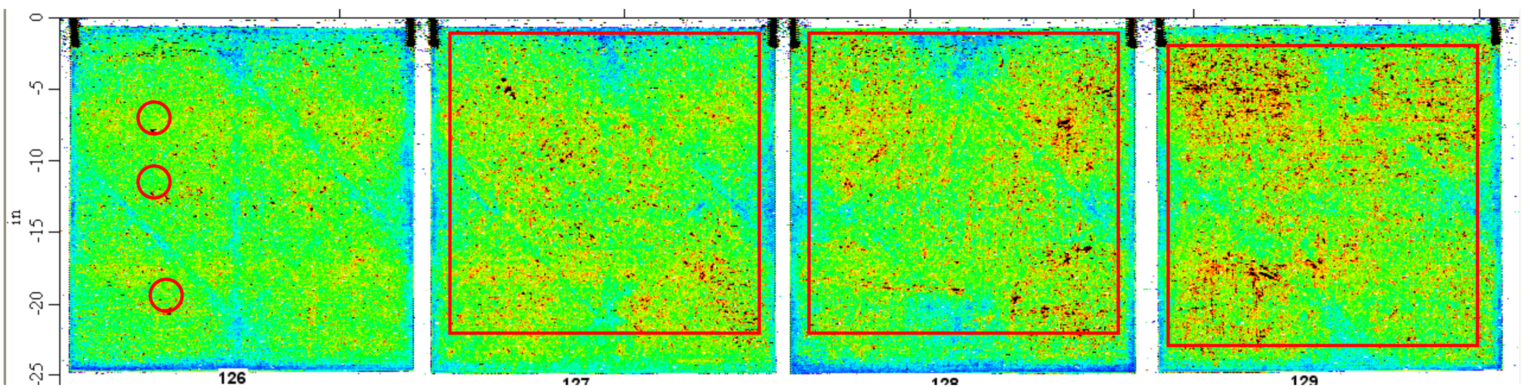


Figure 161. 5 MHz TTU Panel 126, 127, 128, 129

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

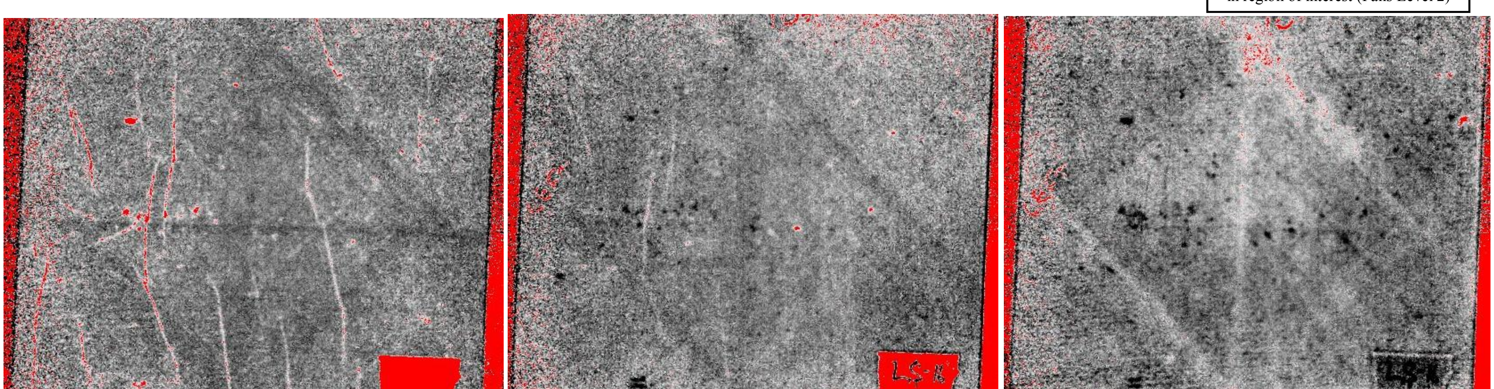


Figure 162. Post-Strike Thermography Back Panel 126 {LS-16} (1st Deriv. – 0.08s, 0.42s, 0.94s)

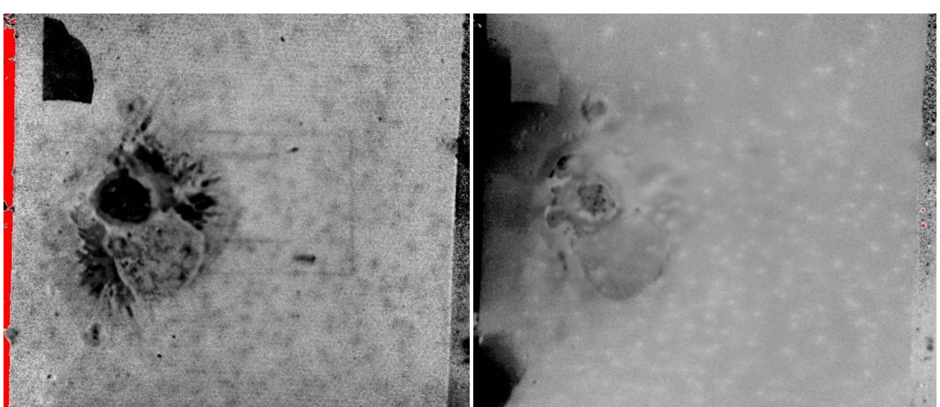


Figure 163. Post-Strike Thermography Front Panel 126 {LS-16} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

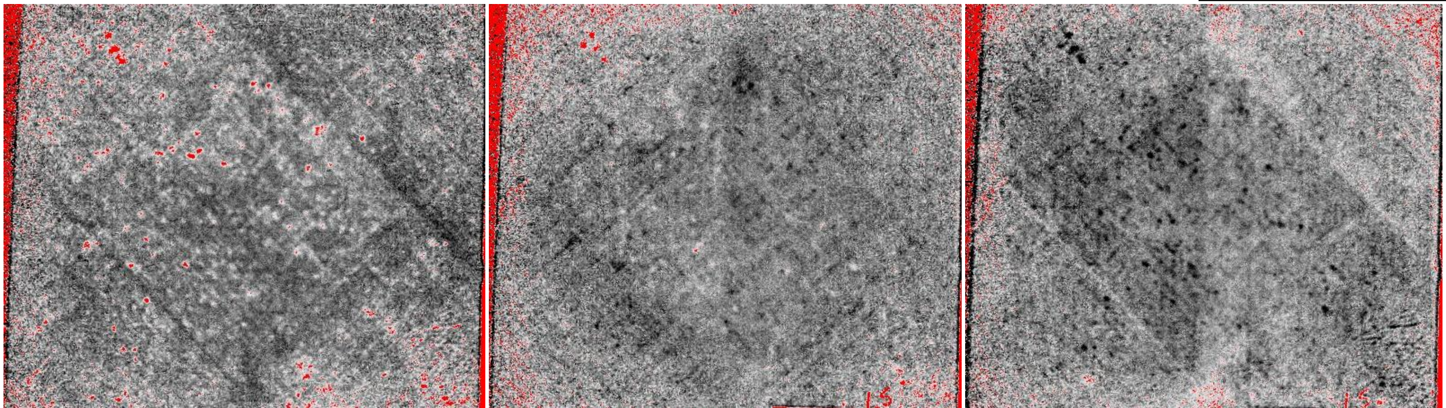


Figure 164. Post-Strike Thermography Back Panel 127 {LS-26} (1st Deriv. – 0.08s, 0.42s, 0.94s)

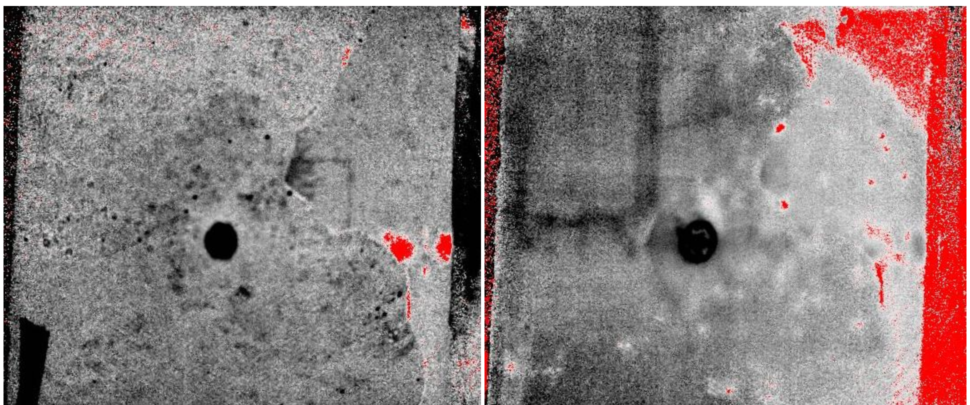


Figure 165. Post-Strike Thermography Front Panel 127 {LS-26} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

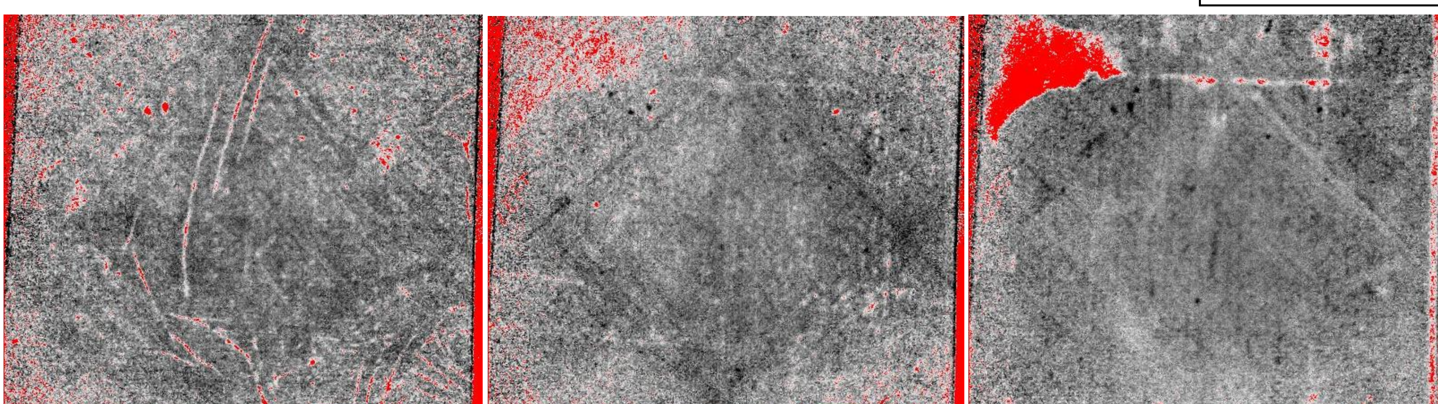


Figure 166. Post-Strike Thermography Back Panel 128 {LS-6} (1st Deriv. – 0.08s, 0.42s, 0.94s)

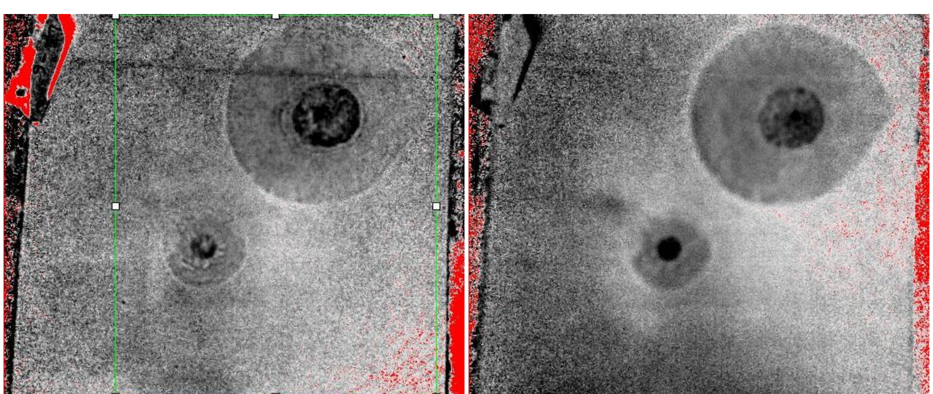


Figure 167. Post-Strike Thermography Front Panel 128 {LS-6} (1st Deriv. – 0.4s & 8.66s)

No Apparent Damage – porosity is high in region of interest (Fails Level 2) ?

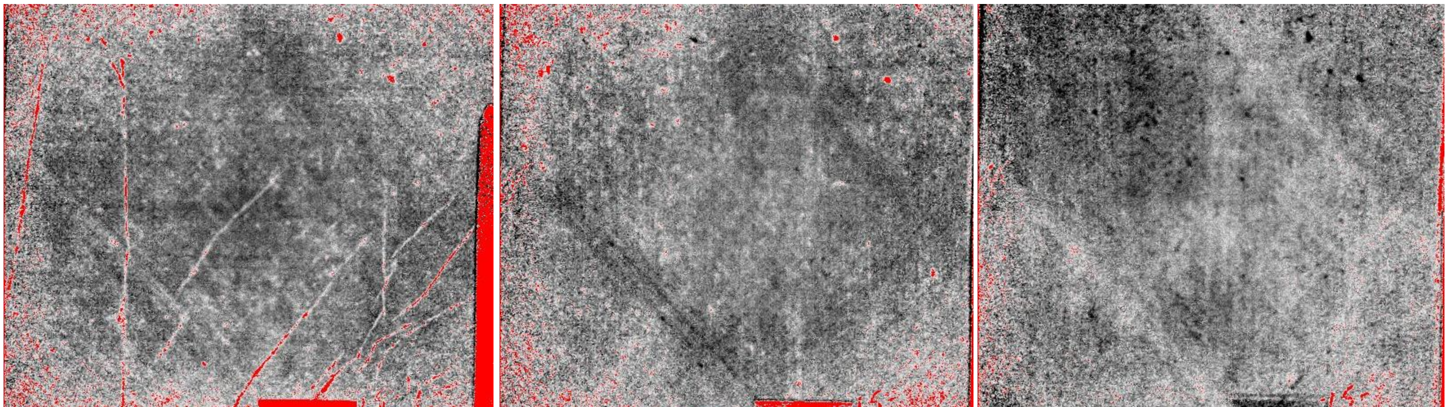


Figure 168. Post-Strike Thermography Back Panel 129 {LS-14} (1^{st} Deriv. – 0.08s, 0.42s, 0.94s)

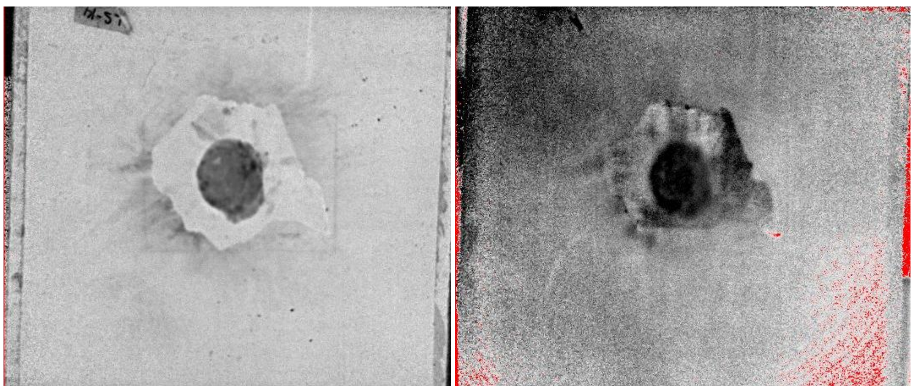


Figure 169. Post-Strike Thermography Front Panel 129 {LS-14} (1^{st} Deriv. – 0.4s & 8.66s)

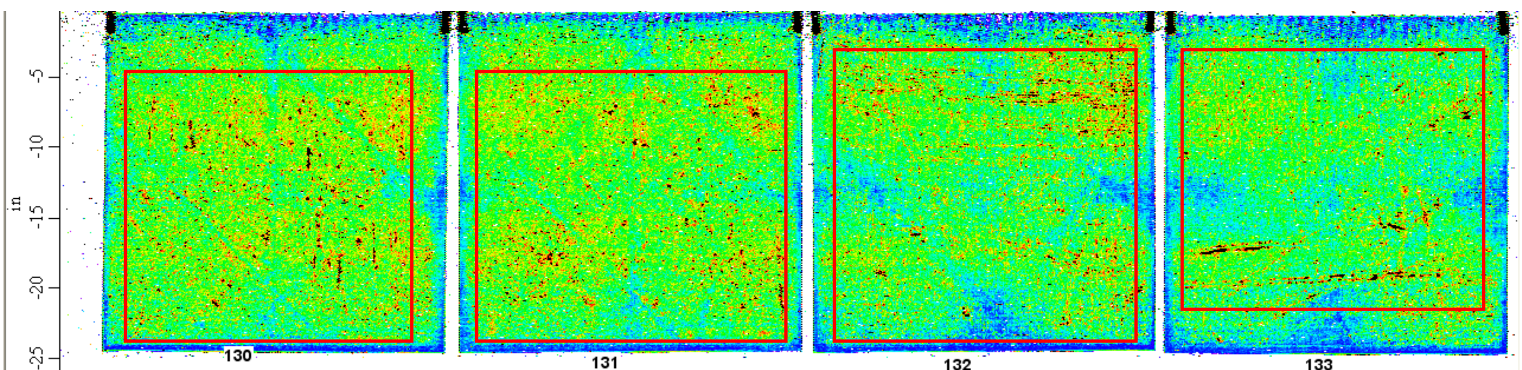


Figure 170. 5 MHz TTU Panel 130, 131, 132, 133

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

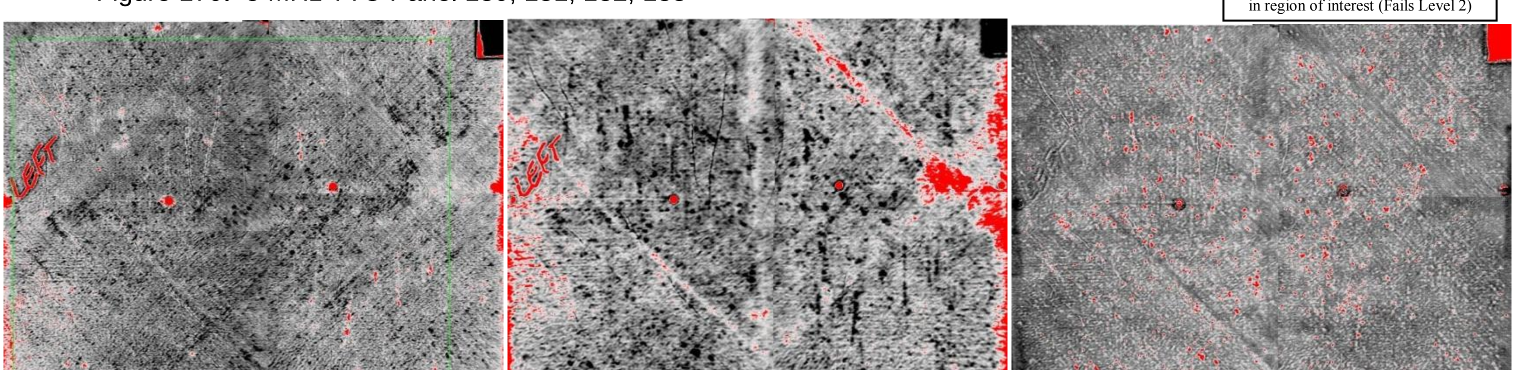


Figure 171. Post-Impact Thermography Panel 130 {IM-70} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

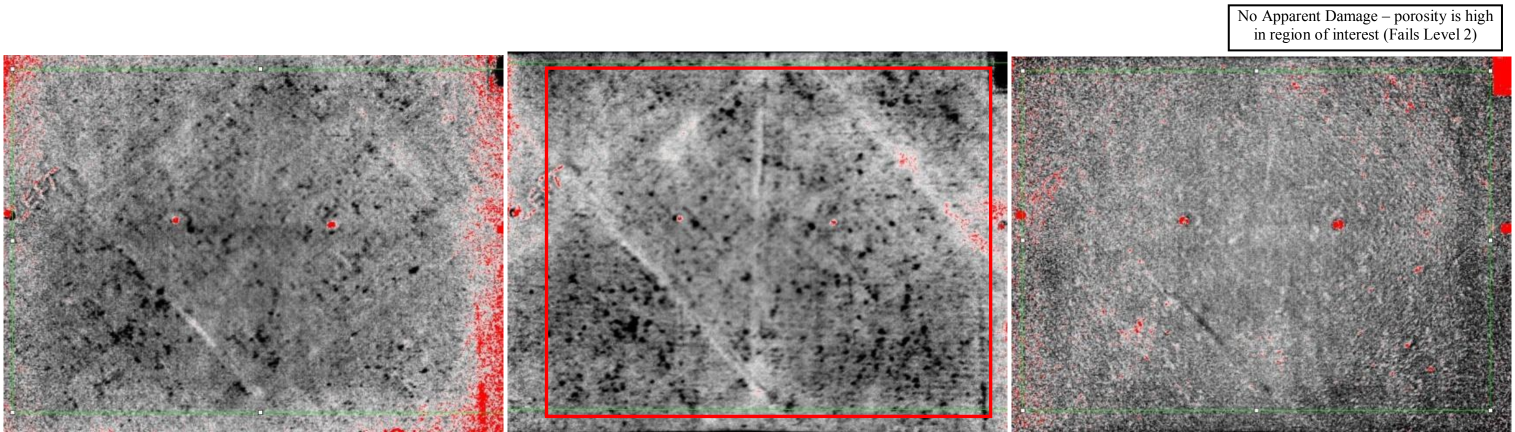


Figure 172. Post-Impact Thermography Panel 131 {IM-11} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

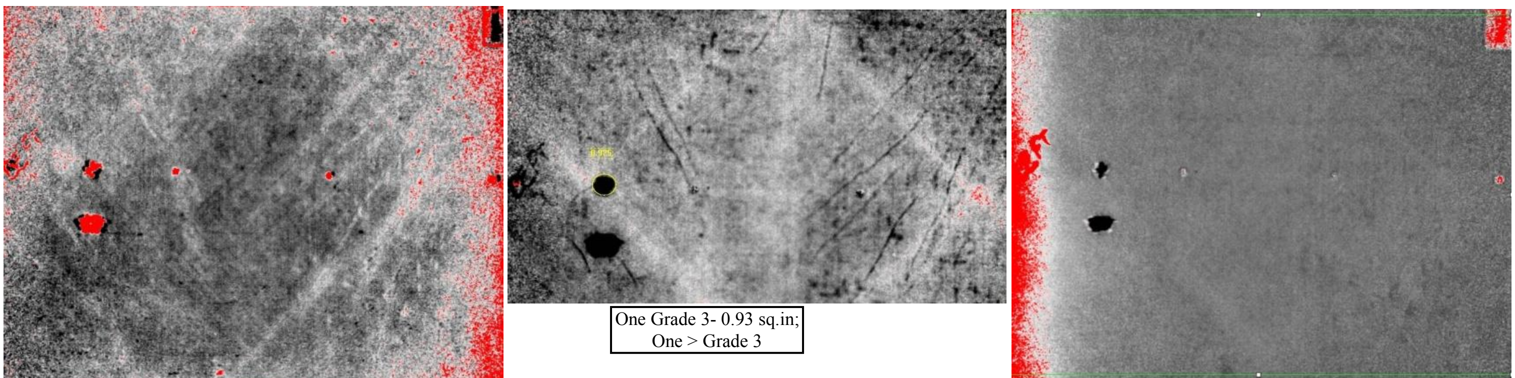


Figure 173. Post-Impact Thermography Panel 132 {IM-98} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

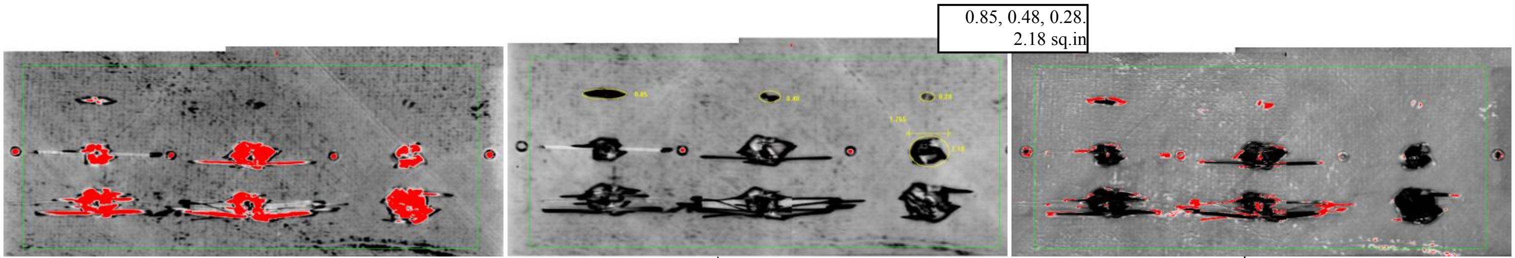


Figure 174. Post-Impact Thermography Bare Panel 133 (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)
< from tool-side, opposite impact surface>

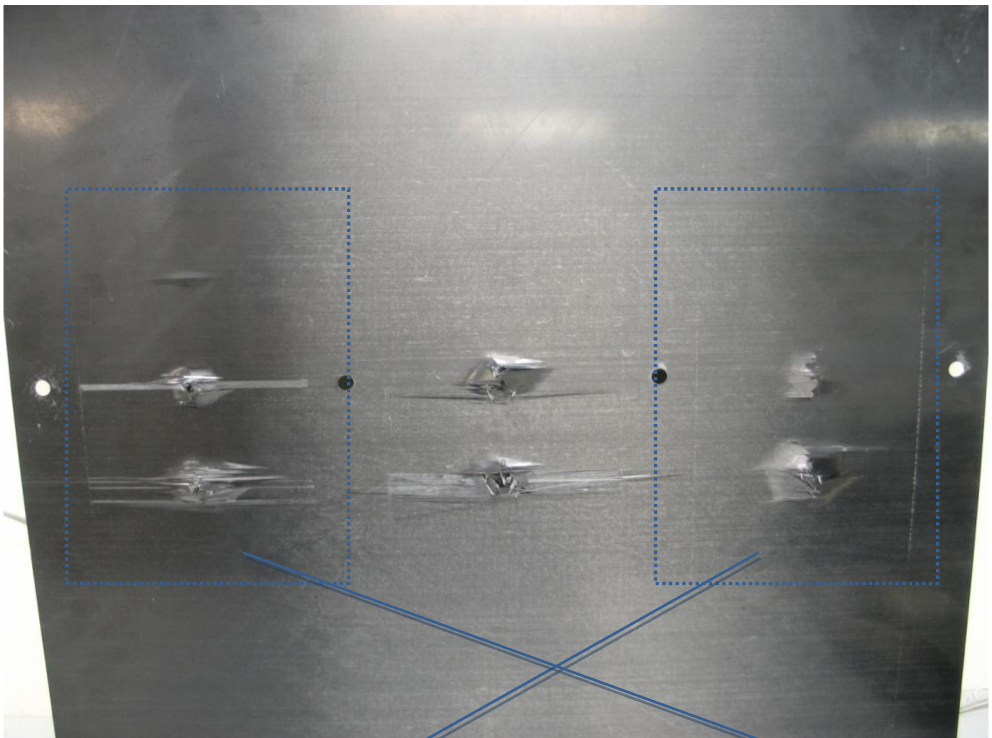


Figure 175. Post-Impact Photo Bare Panel 133 (tool-side, opposite impact surface)

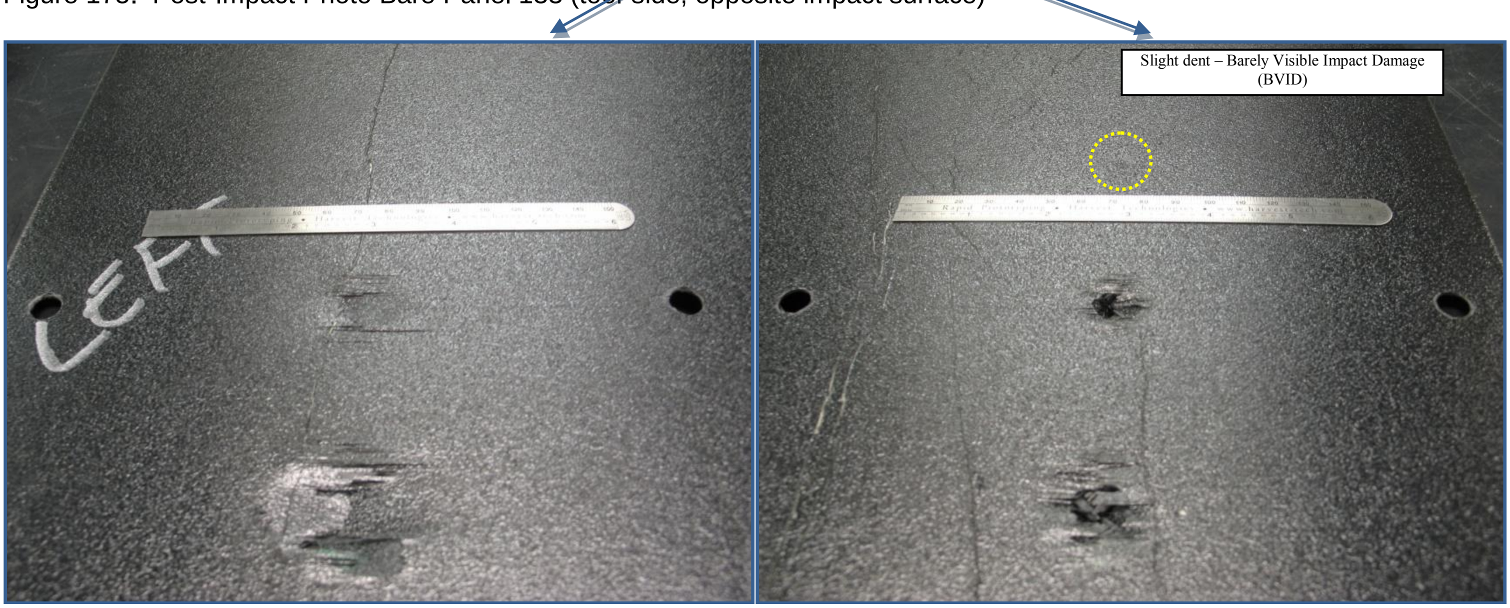


Figure 176. Post-Impact Photo Bare Panel 133 Left & Right Sides (bag-side impact surface)

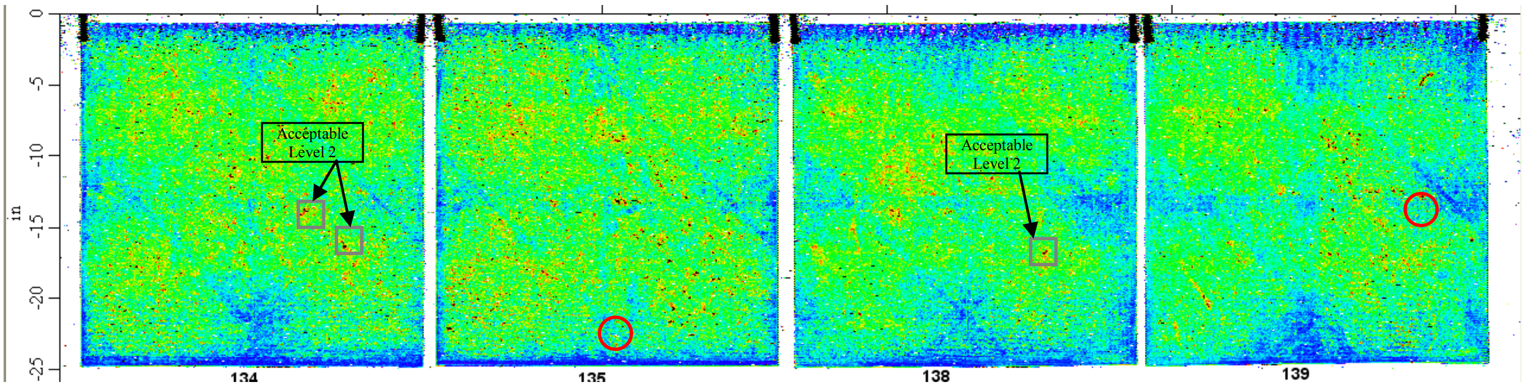


Figure 177. 5 MHz TTU Panel 134, 135, 138, 139

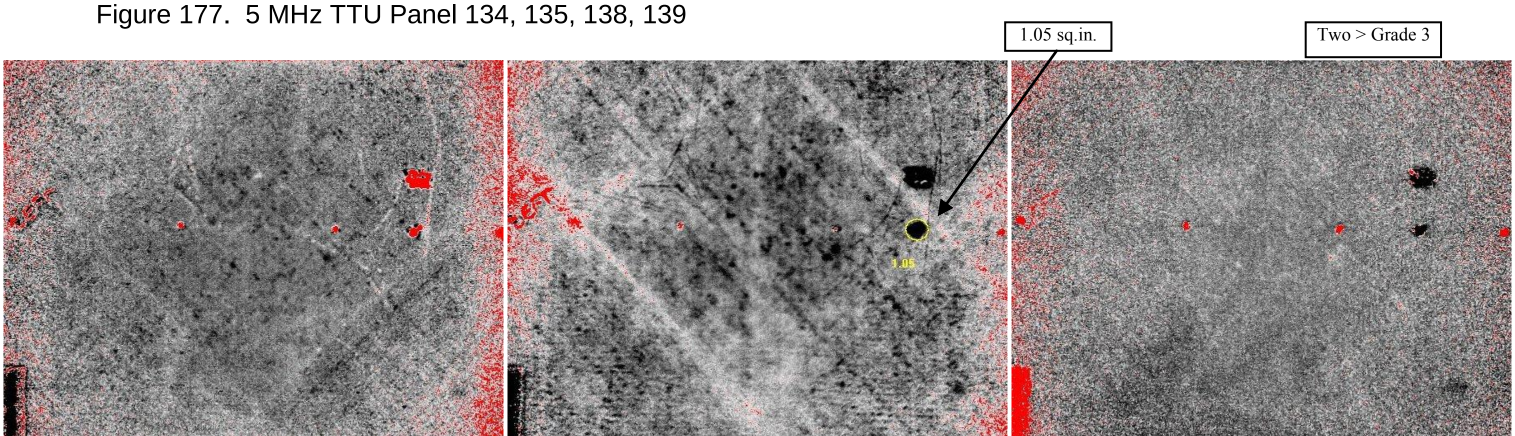


Figure 178. Post-Impact Thermography Panel 134 {IM-75} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

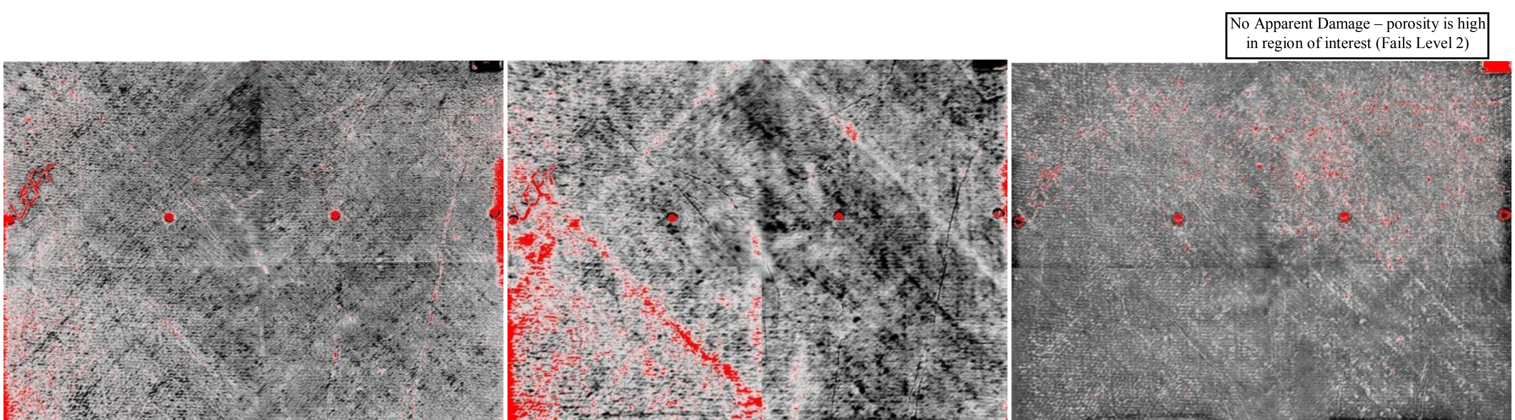


Figure 179. Post-Impact Thermography Panel 135 {IM-30} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

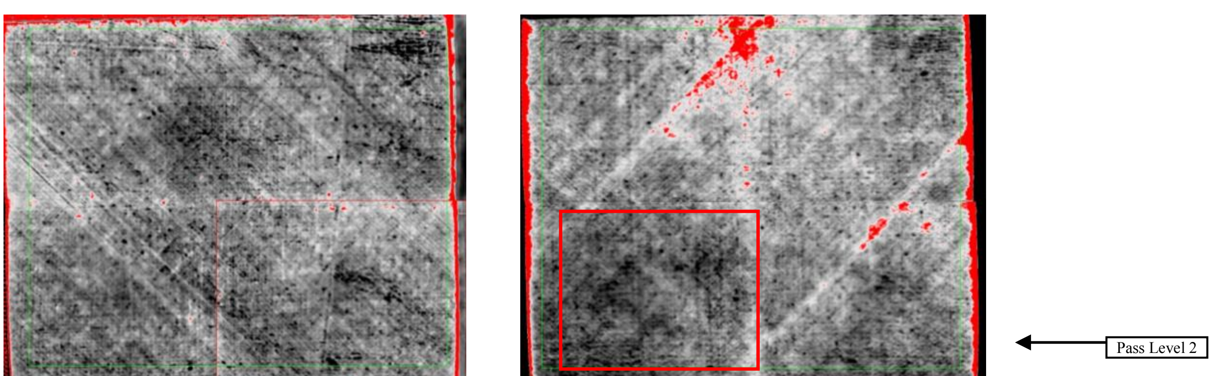


Figure 180. Thermography Panel AS136 (1st Deriv. - 0.42 & 0.94 sec)

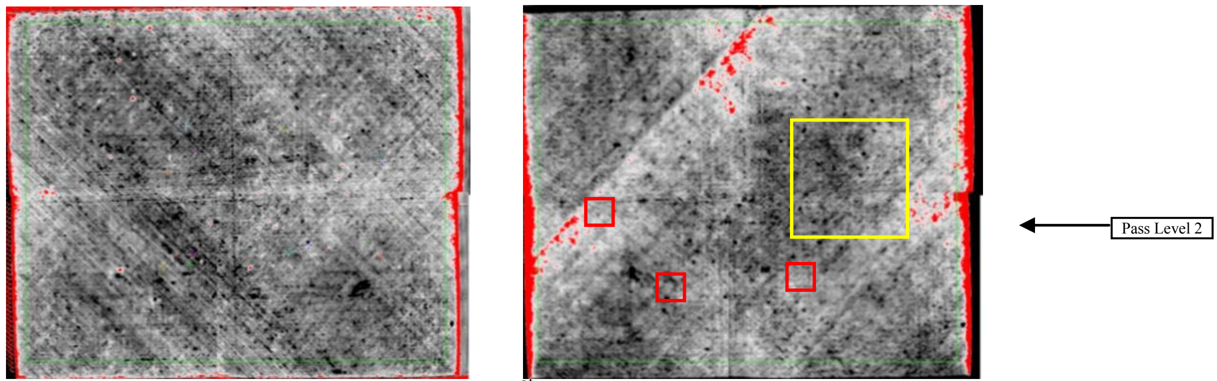


Figure 181. Thermography Panel AS137 (1st Deriv. - 0.42 & 0.94 sec)

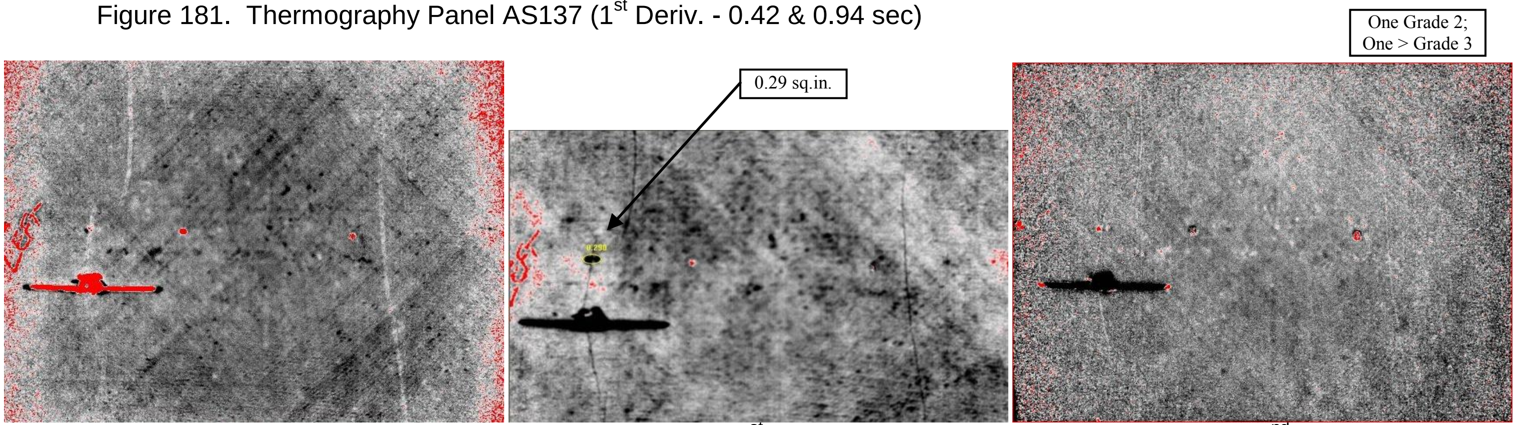


Figure 182. Post-Impact Thermography Panel 138 {IM-60} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

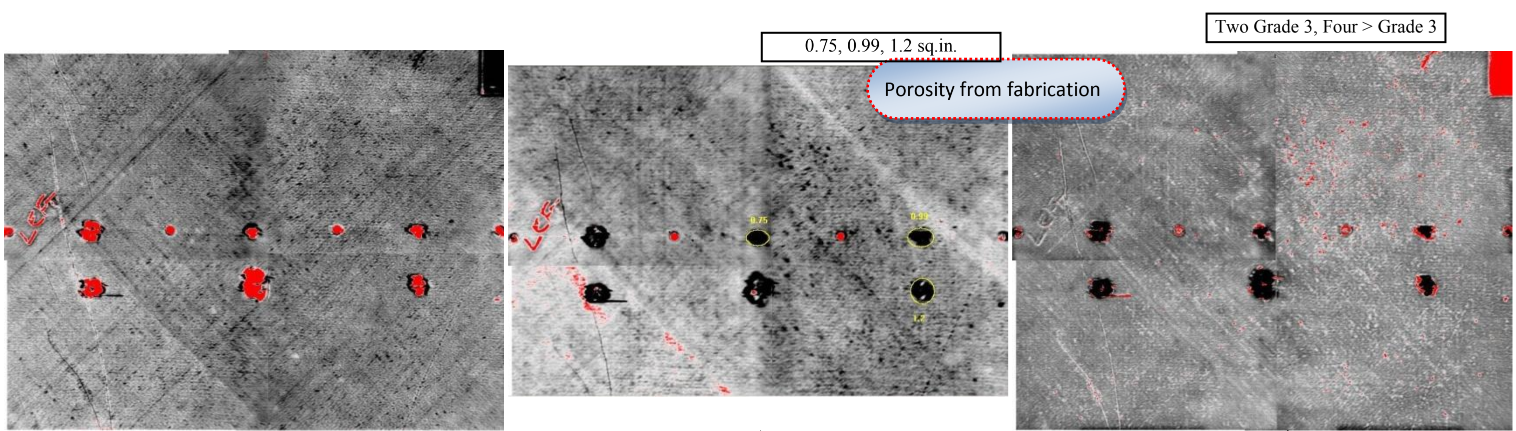


Figure 183. Post-Impact Thermography Panel 139 {IM-95} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

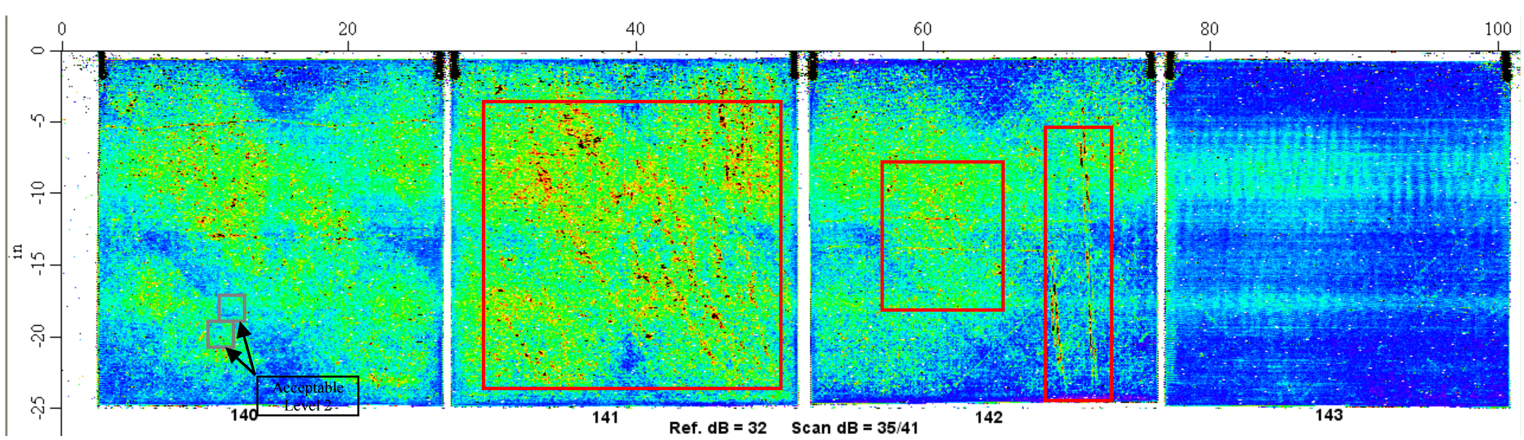


Figure 184. 5 MHz TTU Panel 140, 141, 142, 143

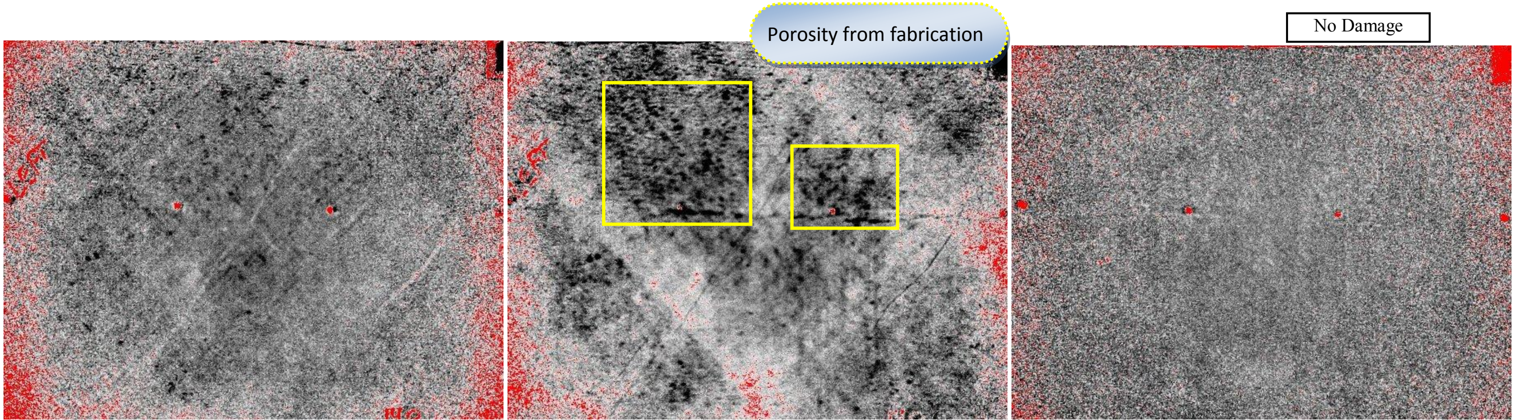


Figure 185. Post-Impact Thermography Panel 140 {IM-83} (1^{st} Deriv. - 0.42, 0.94s & Peak Ampl)

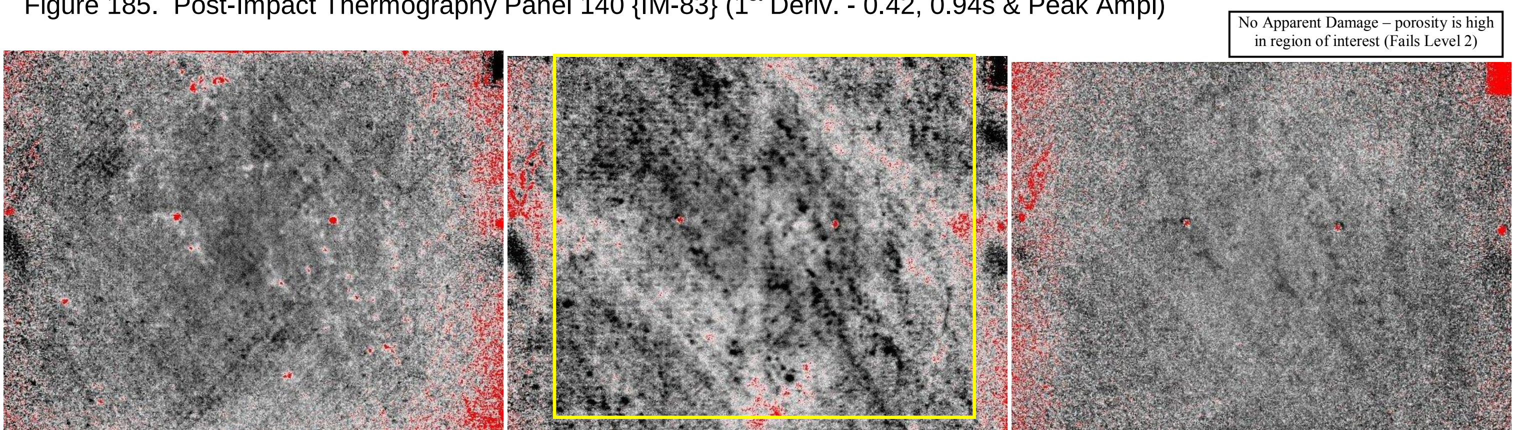


Figure 186. Post-Impact Thermography Panel 141 {IM-41} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

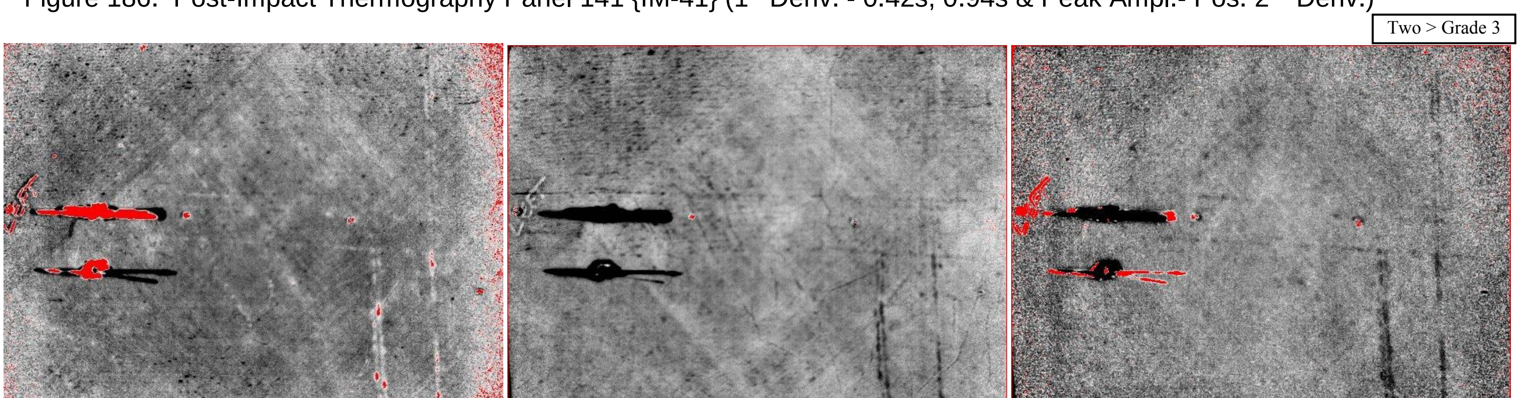


Figure 187. Post-Impact Thermography Panel 142 {IM-63} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

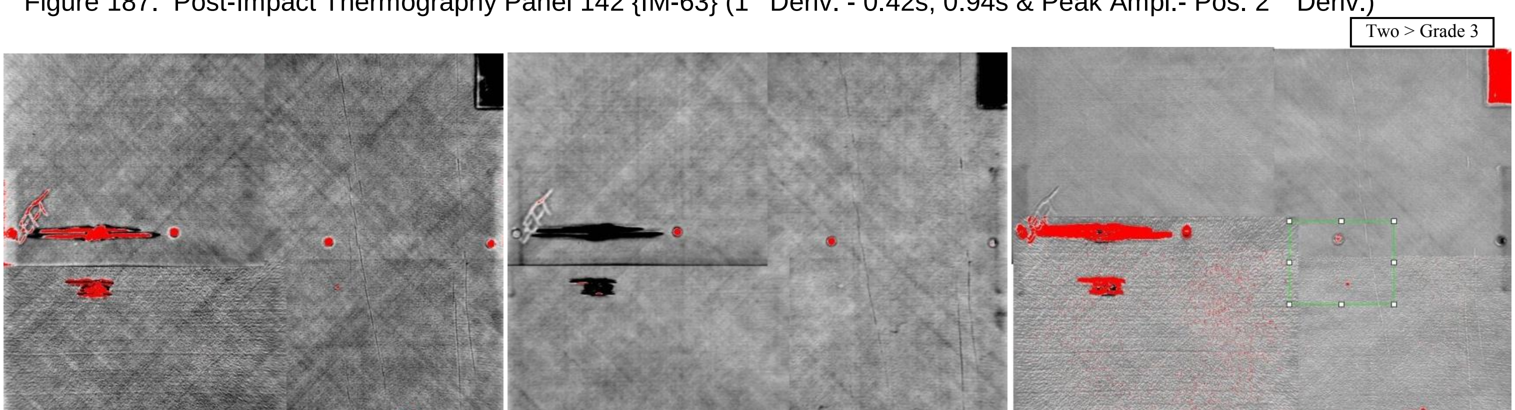


Figure 188. Post-Impact Thermography Panel 143 {IM-52} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

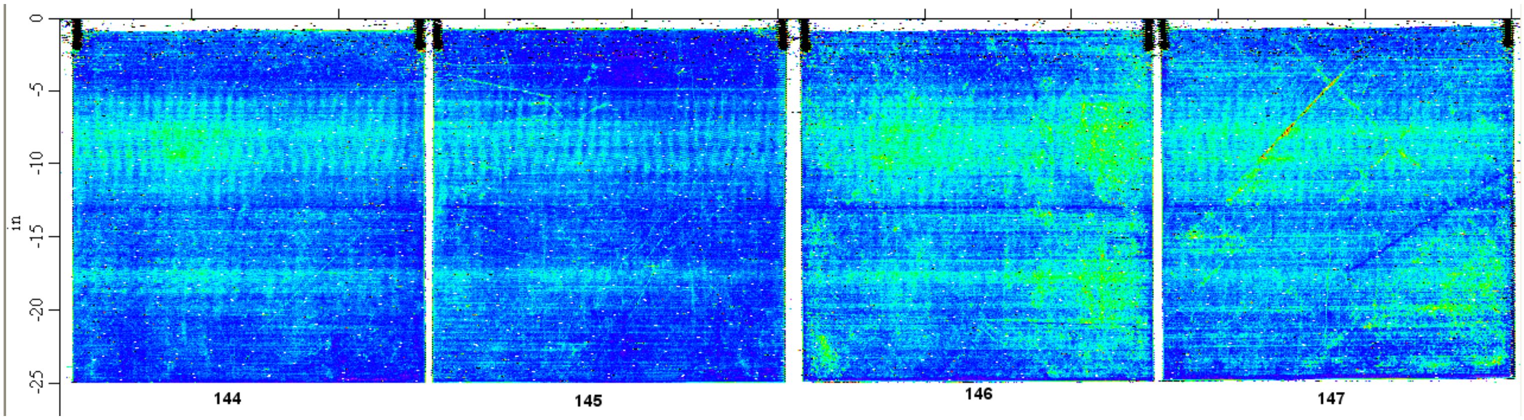


Figure 189. 5 MHz TTU Panel 144, 145, 146, 147

Two > Grade 3

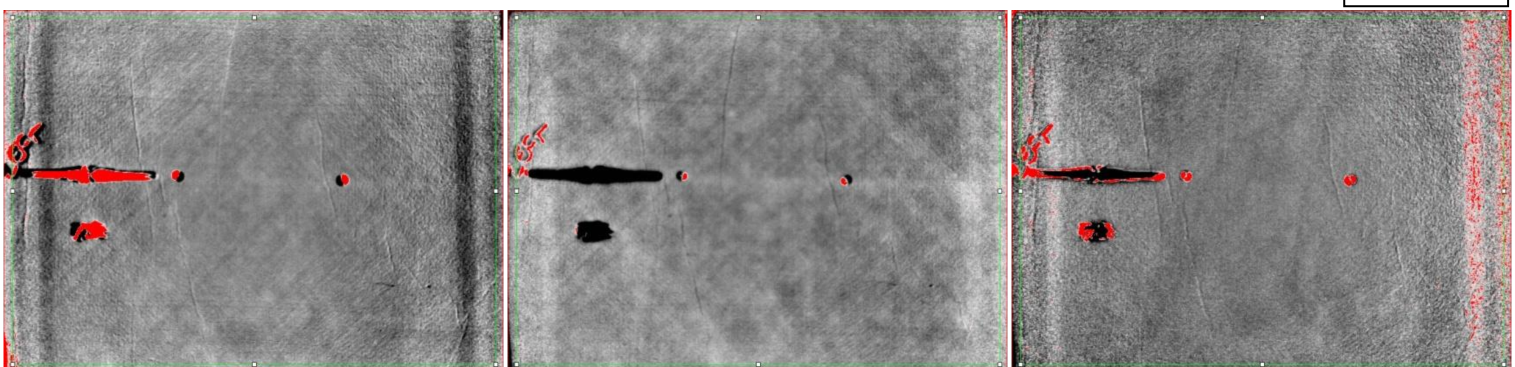


Figure 190. Post-Impact Thermography Panel 144 {IM-73} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

No Damage

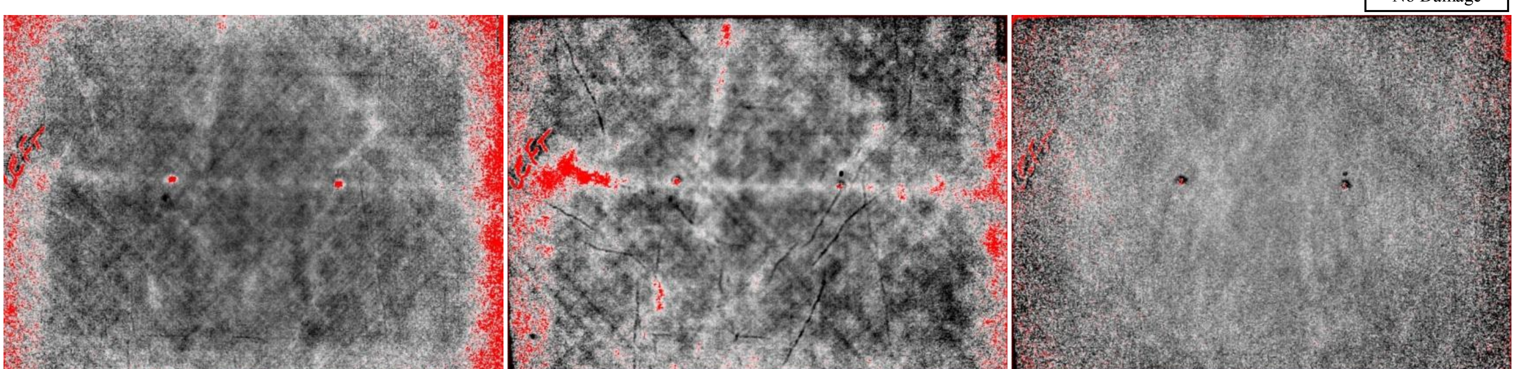


Figure 191. Post-Impact Thermography Panel 145 {IM-31} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

No Damage

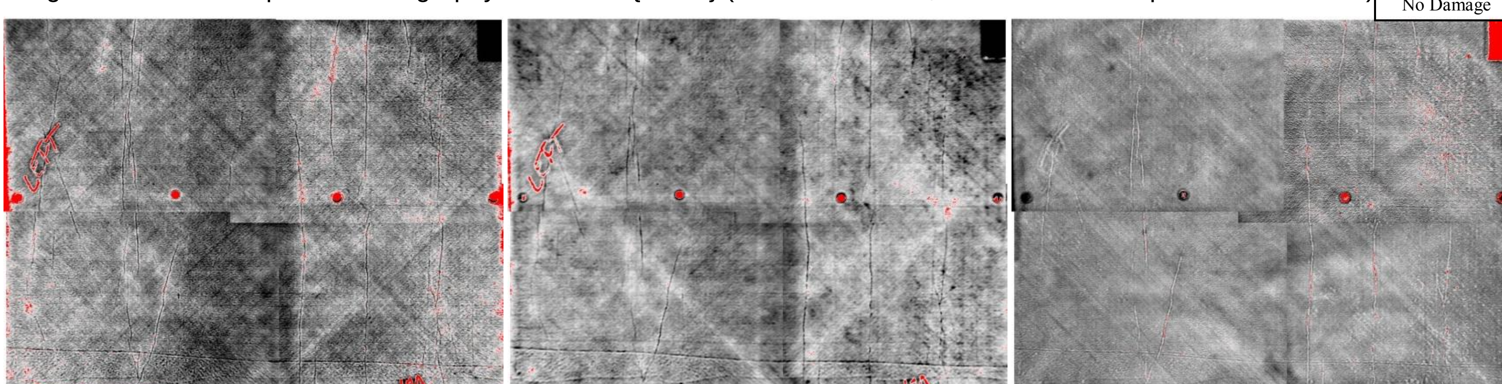


Figure 192. Post-Impact Thermography Panel 146 {IM-12} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

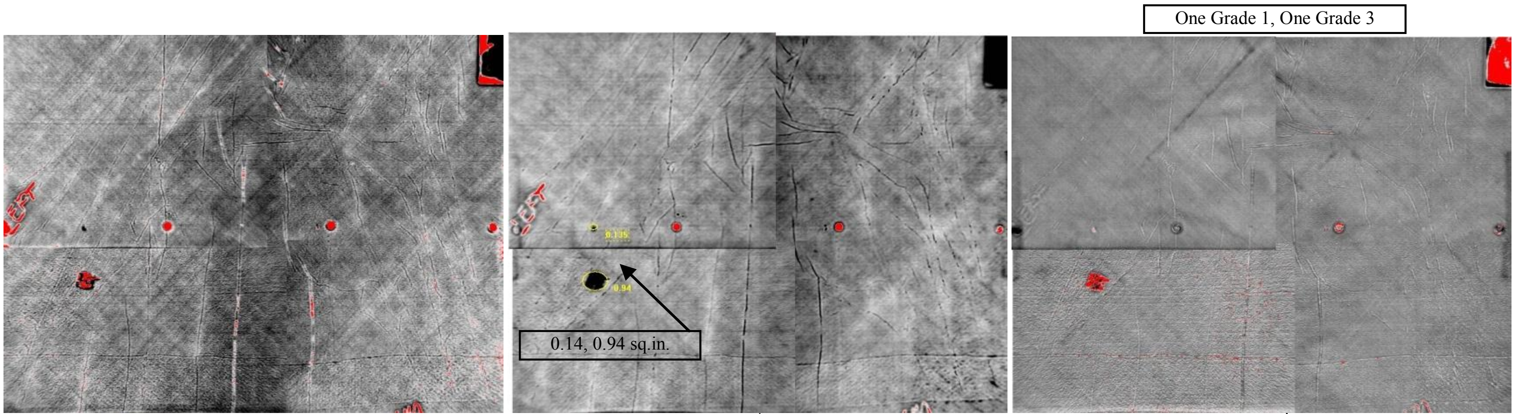


Figure 193. Post-Impact Thermography Panel 147 {IM-56} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

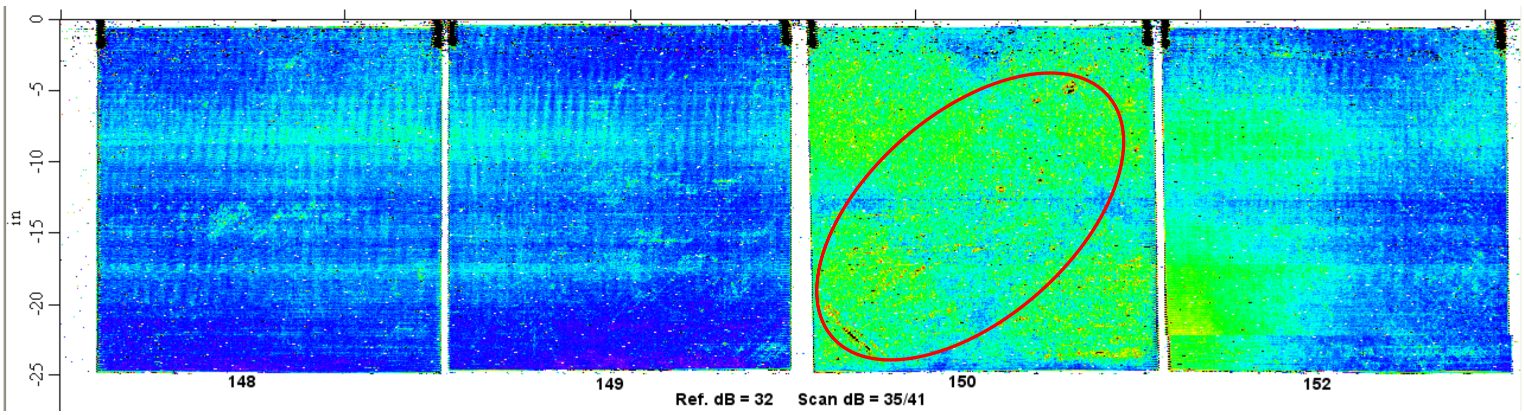


Figure 194. 5 MHz TTU Panel 148, 149, 150, 151

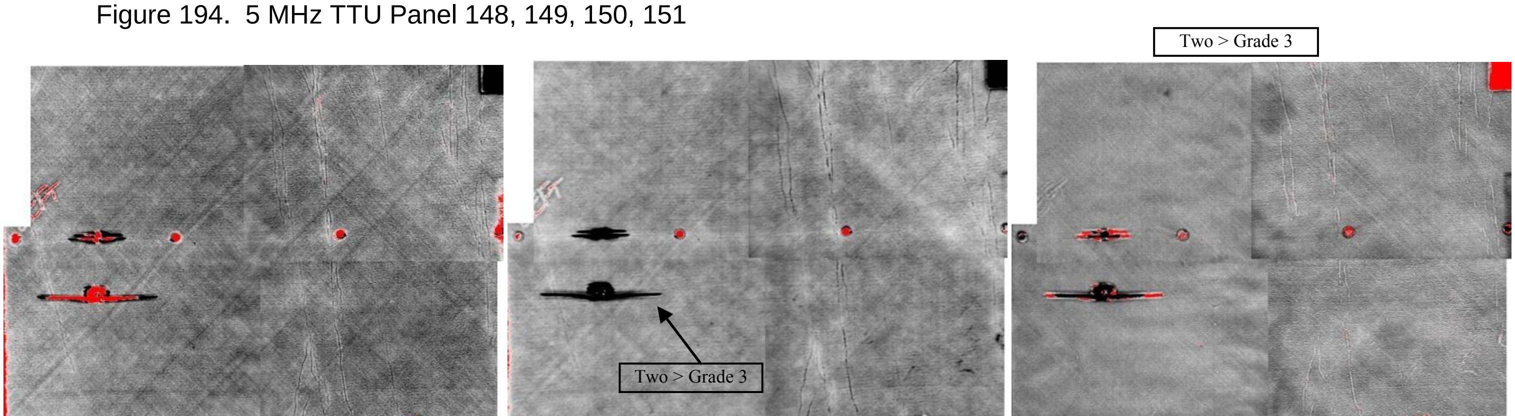


Figure 195. Post-Impact Thermography Panel 148 {IM-2} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

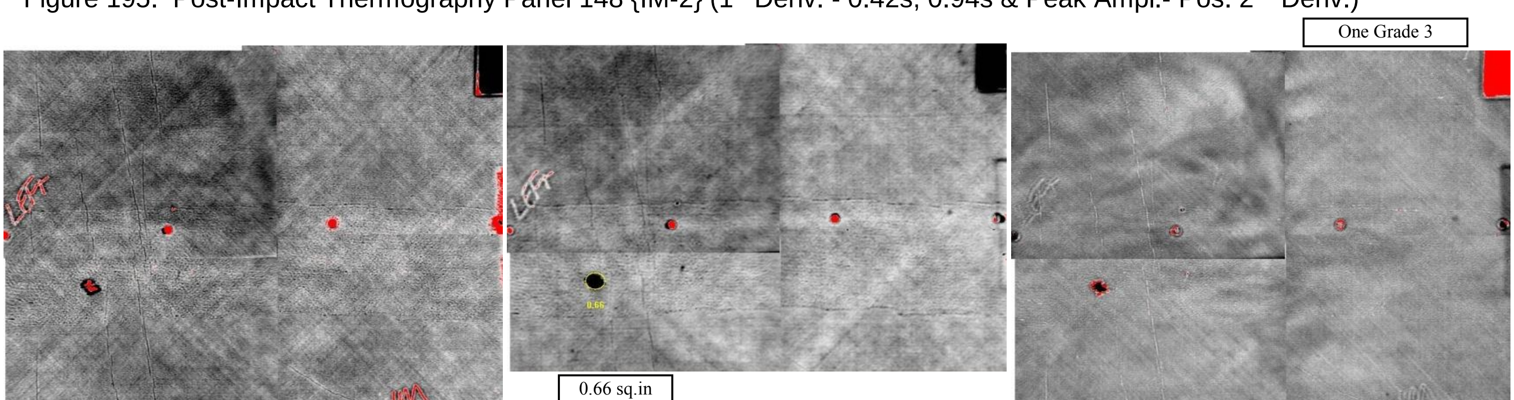


Figure 196. Post-Impact Thermography Panel 149 {IM-19} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

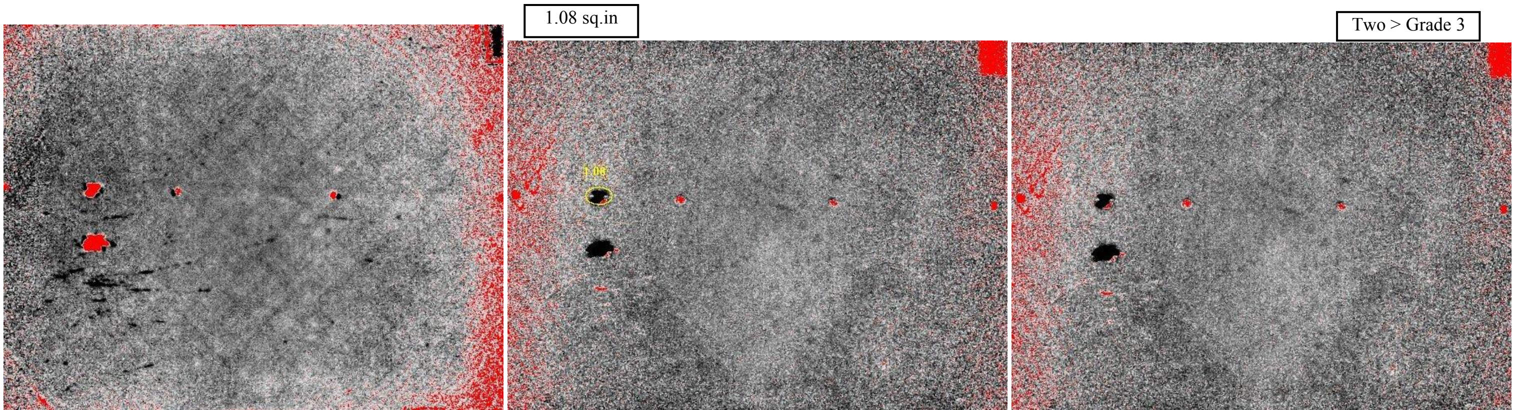


Figure 197. Post-Impact Thermography Panel 150 {IM-66} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

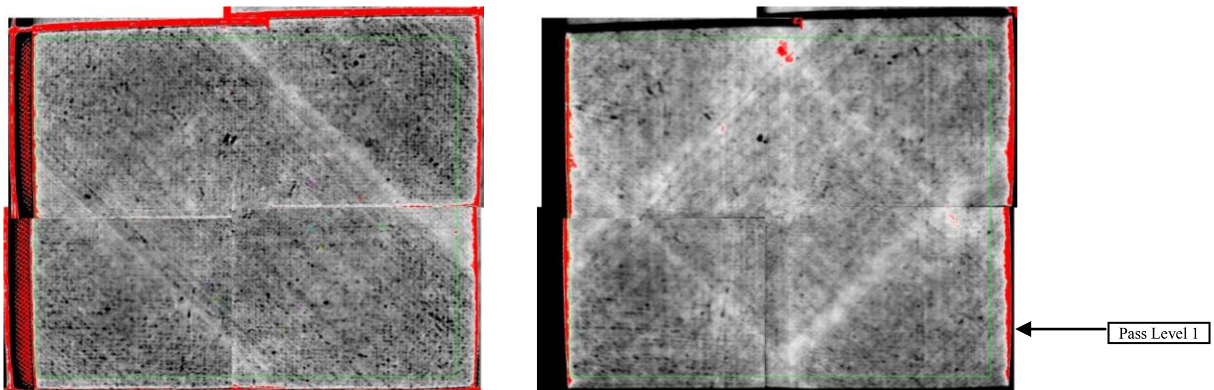


Figure 198. Thermography Panel AS151 (1st Deriv. - 0.42 & 0.94 sec)

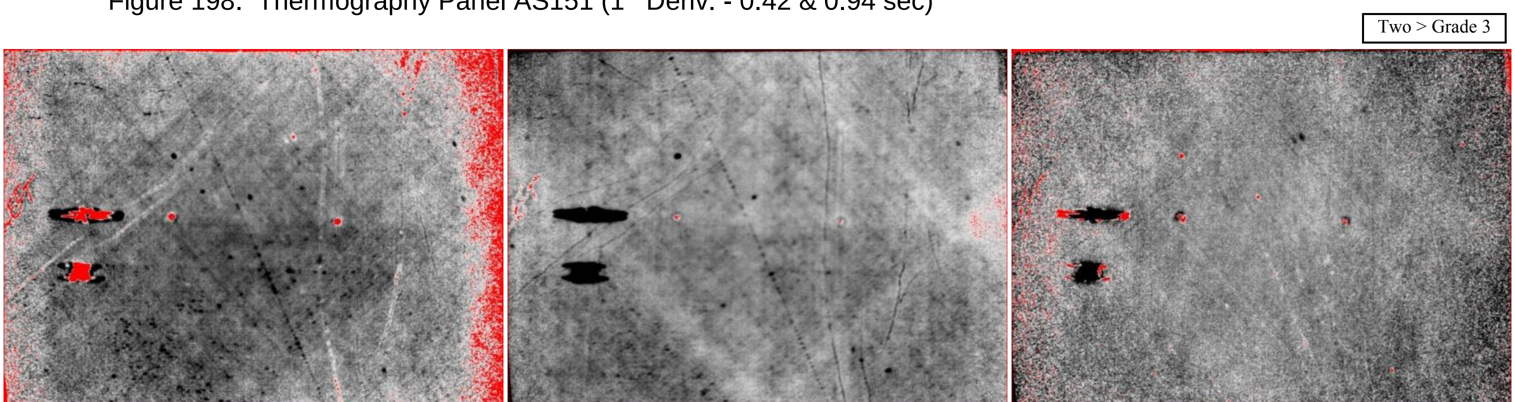


Figure 199. Post-Impact Thermography Panel 151 {IM-81} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

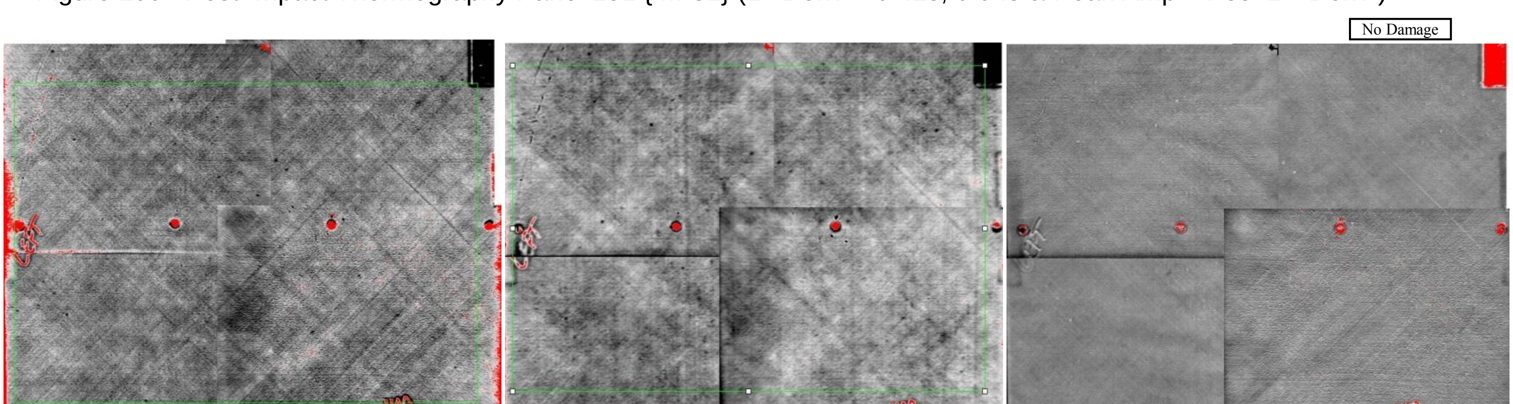


Figure 200. Post-Impact Thermography Panel 152 {IM-37} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

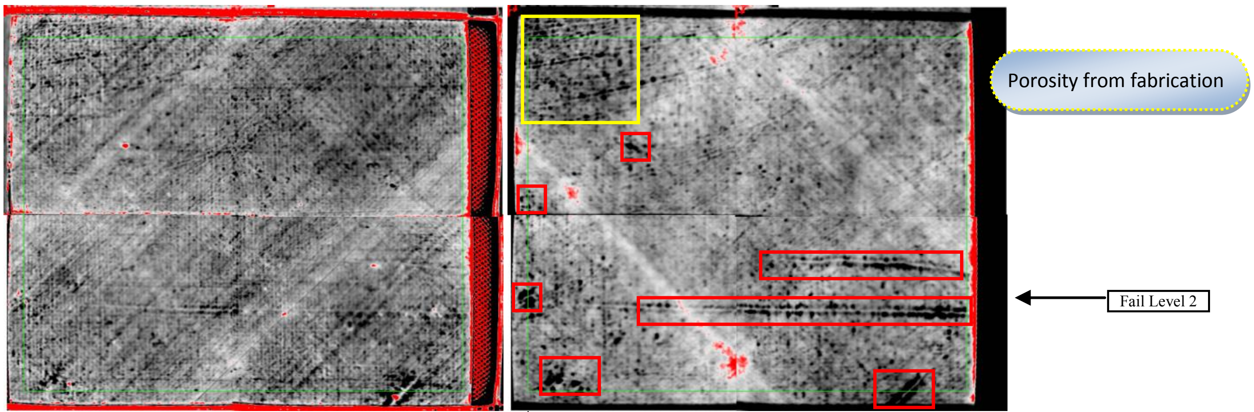


Figure 201. Thermography Panel AS153 (1^{st} Deriv. - 0.42 & 0.94 sec) <mirrored from tool-side>

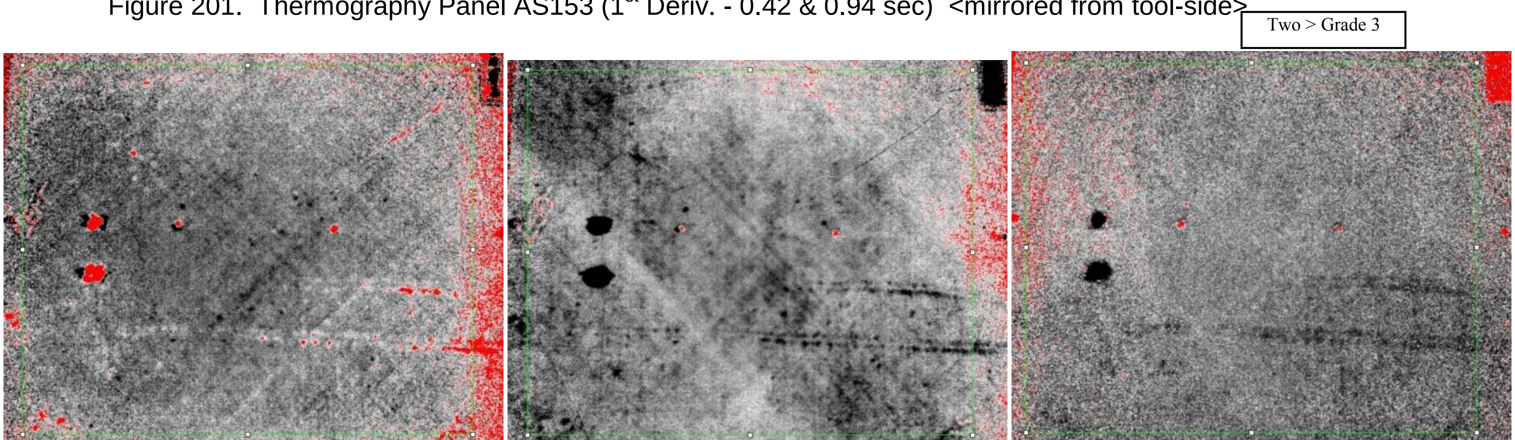


Figure 202. Post-Impact Thermography Panel 153 {IM-46} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

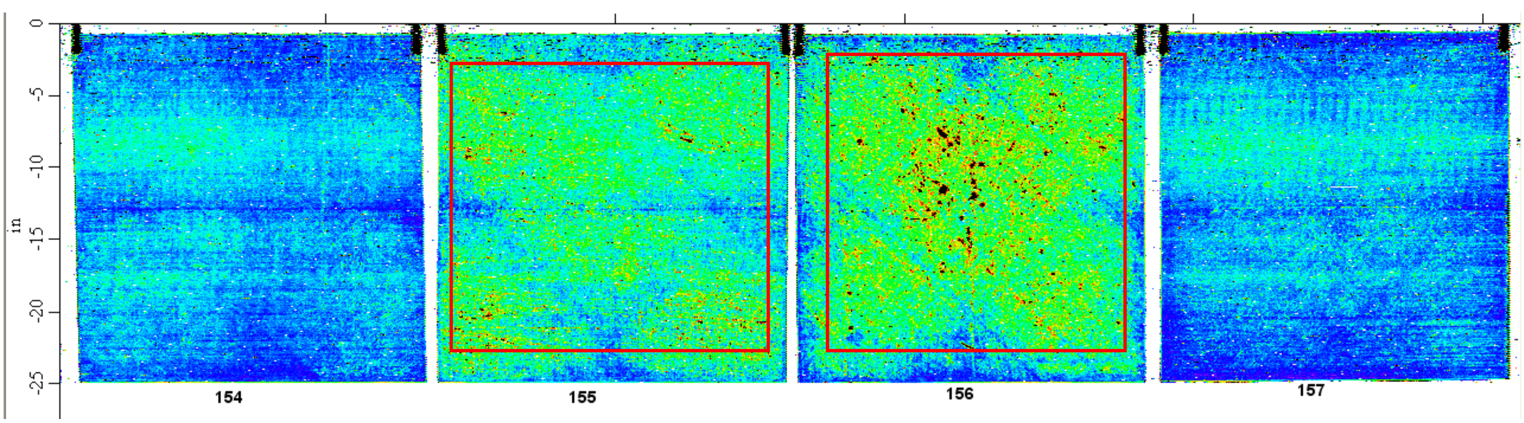


Figure 203. 5 MHz TTU Panel 154, 155, 156, 157

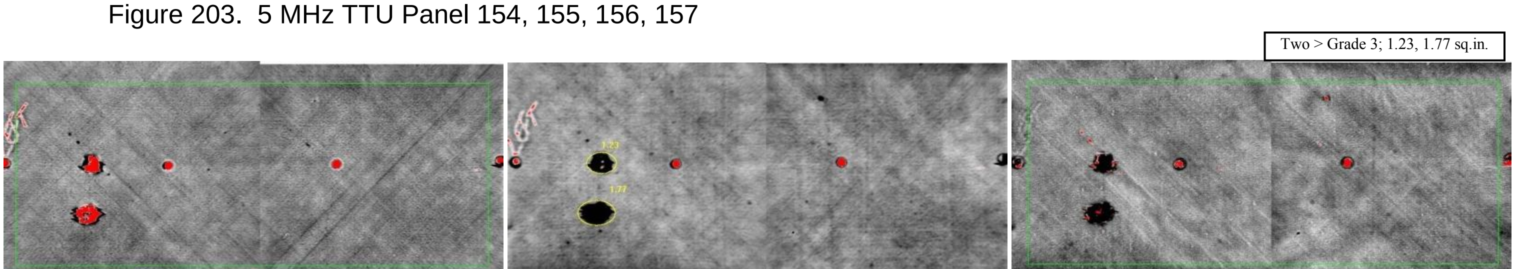


Figure 204. Post-Impact Thermography Panel 154 {IM-91} (1^{st} Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2^{nd} Deriv.)

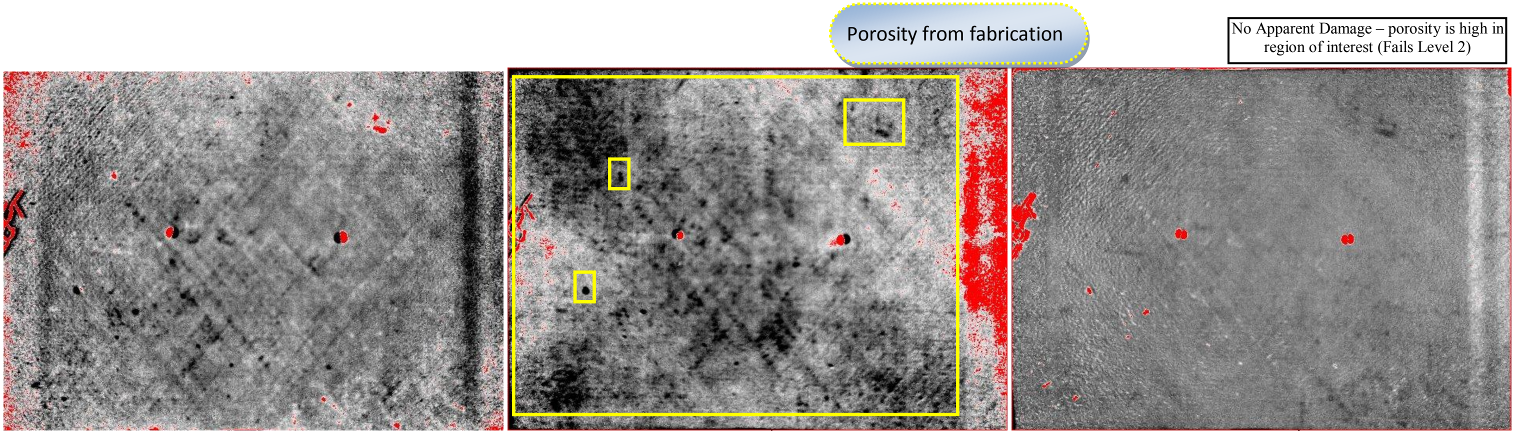


Figure 205. Post-Impact Thermography Panel 155 {IM-69} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

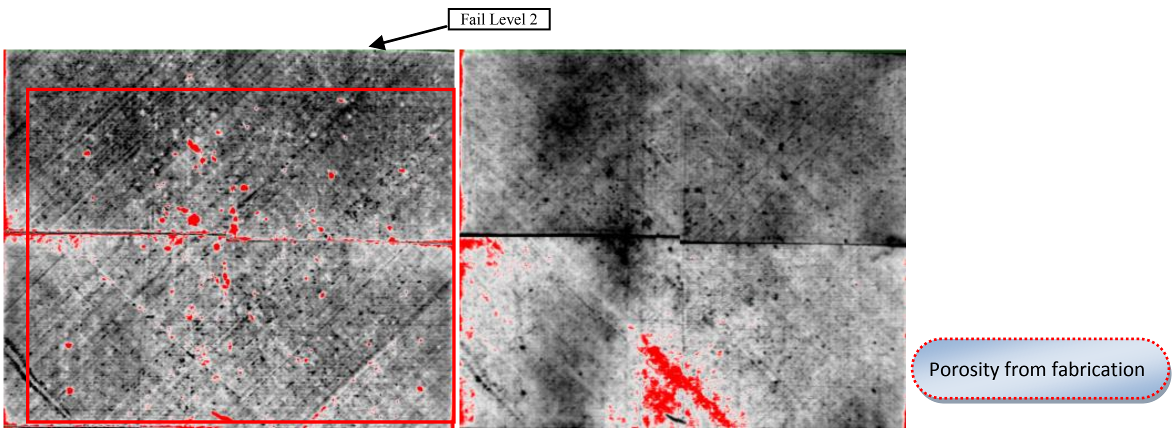


Figure 206. Thermography Panel 156 (1st Deriv. - 0.42 & 0.94 sec)

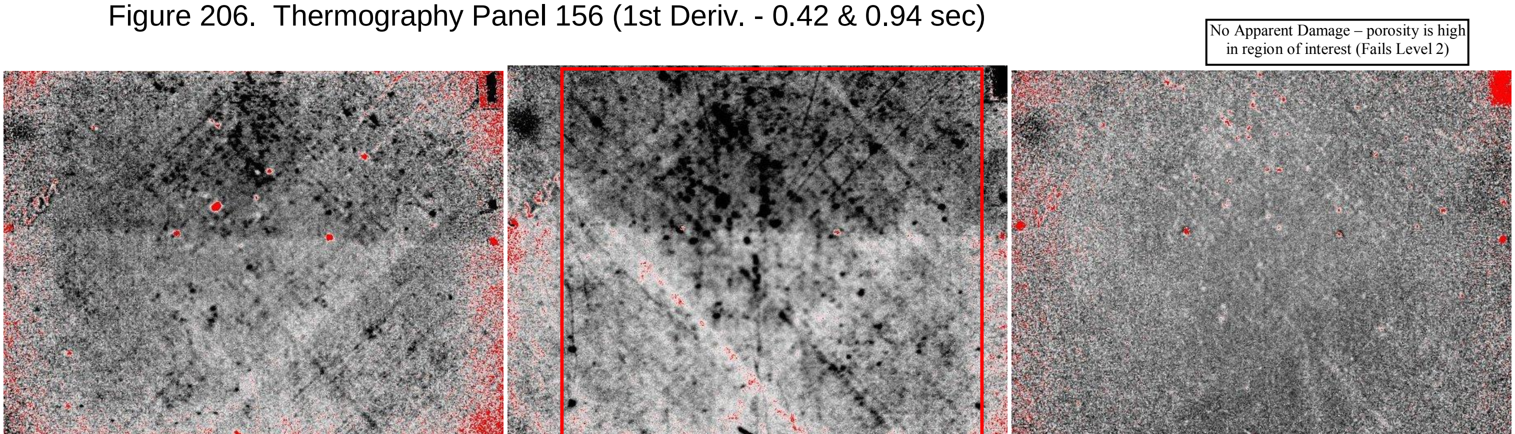


Figure 207. Post-Impact Thermography Panel 156 {IM-82} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

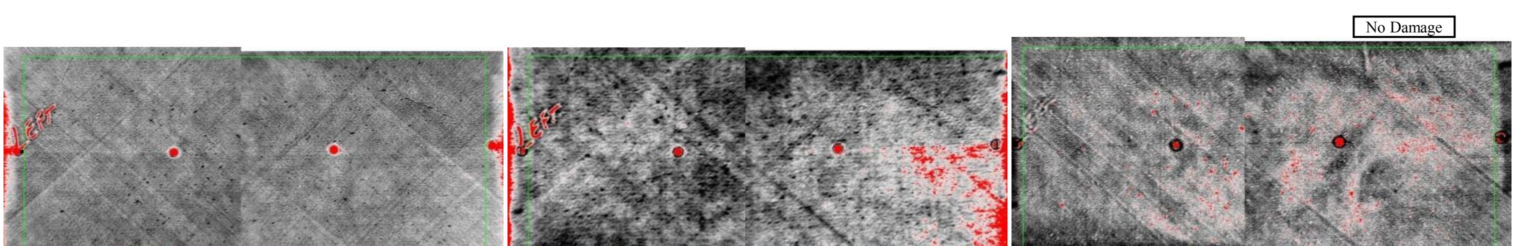


Figure 208. Post-Impact Thermography Panel 157 {IM-9} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

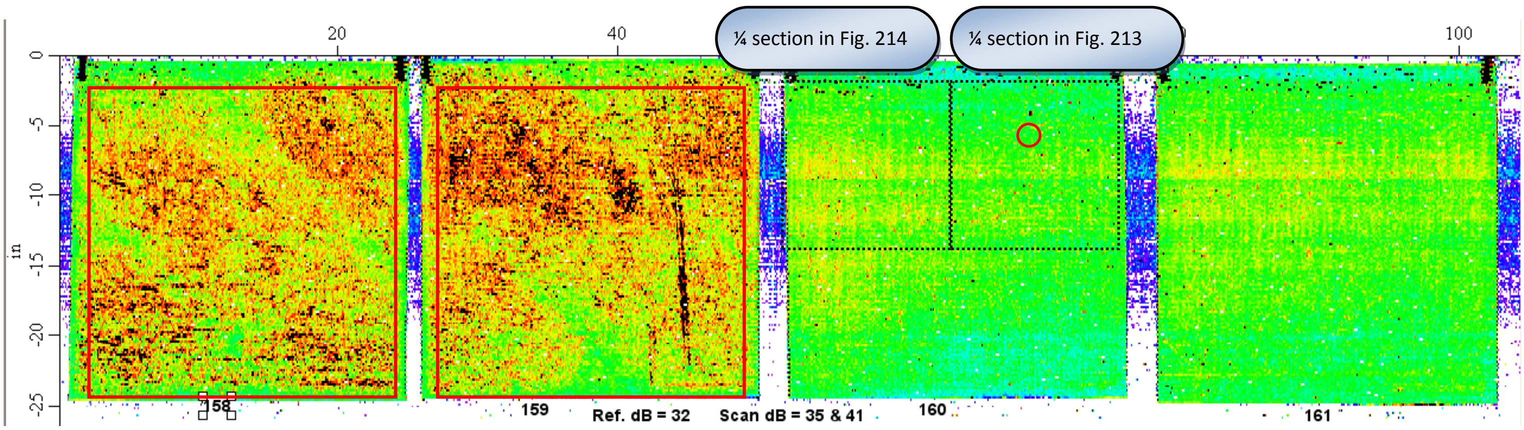


Figure 209. 5 MHz TTU Panel 158, 159, 160, 161

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

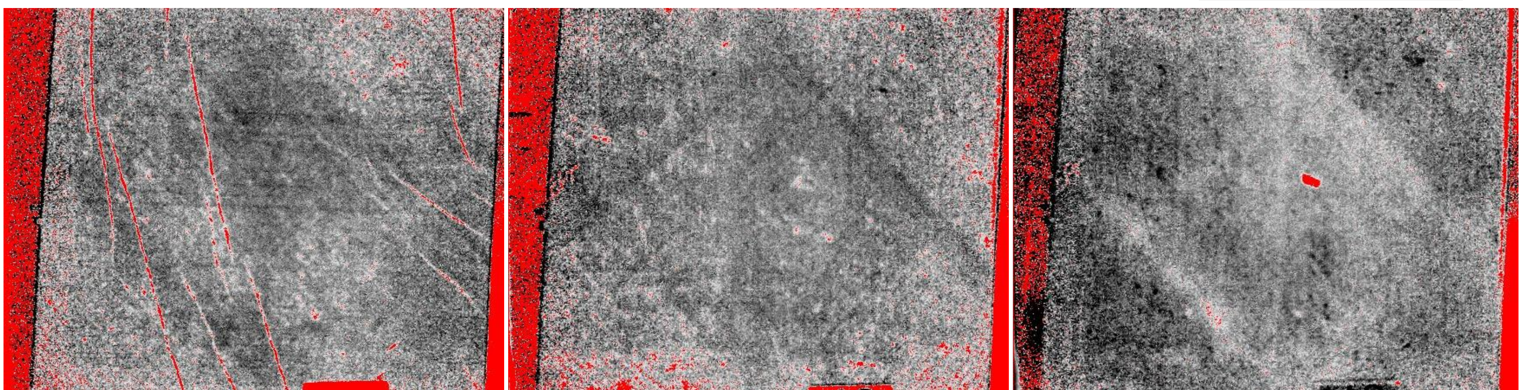


Figure 210. Post-Strike Thermography Back Panel 158 {LS-2} (1st Deriv. – 0.08s, 0.42s, 0.94s)

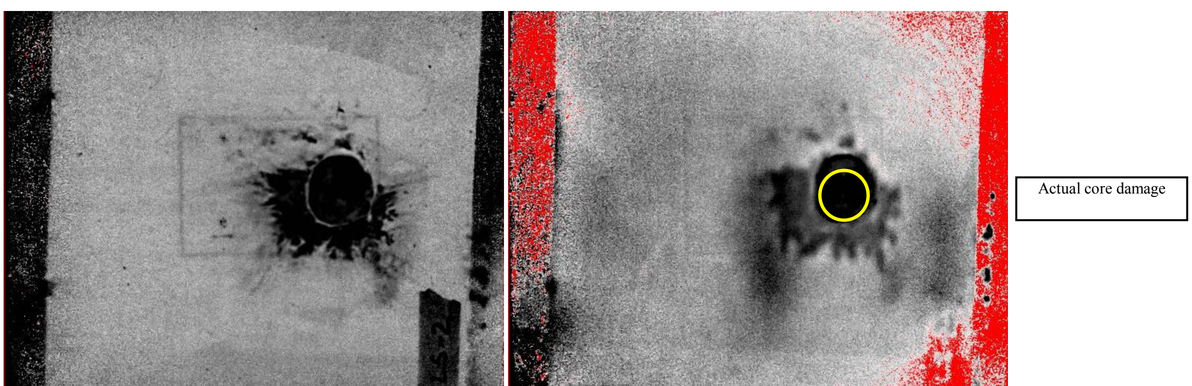


Figure 211. Post-Strike Thermography Front Panel 158 {LS-2} (1st Deriv. – 0.4s & 8.66s)

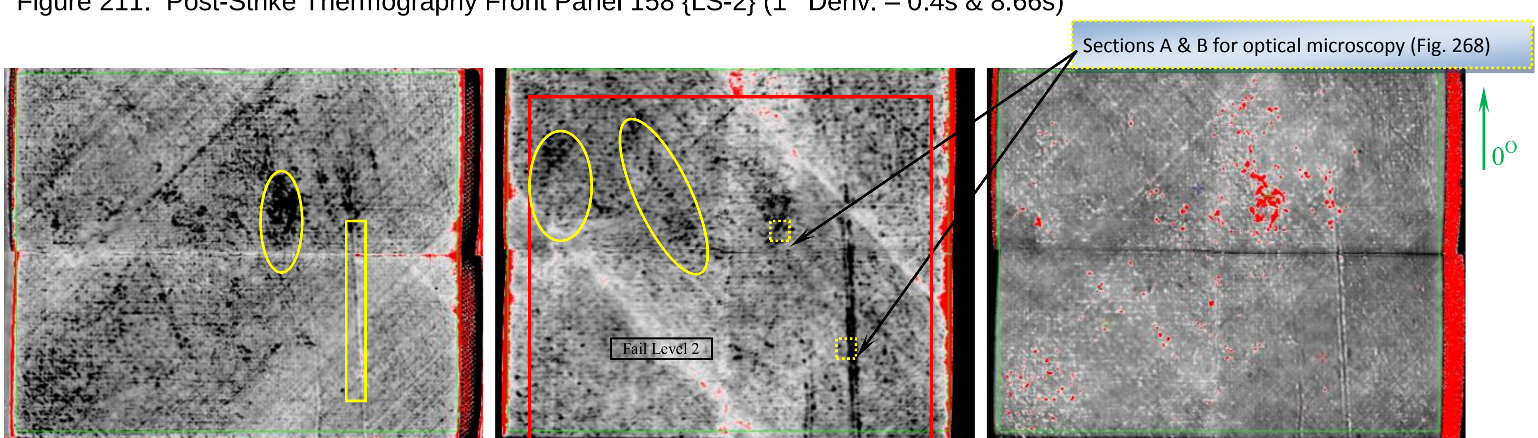


Figure 212. Thermography 159 (1st Deriv. 0.42 & 0.94 sec and Peak Ampl.- Pos. 2nd Deriv)

Scattered porosity

Initial impact test results on Panel 160 quarter sections:

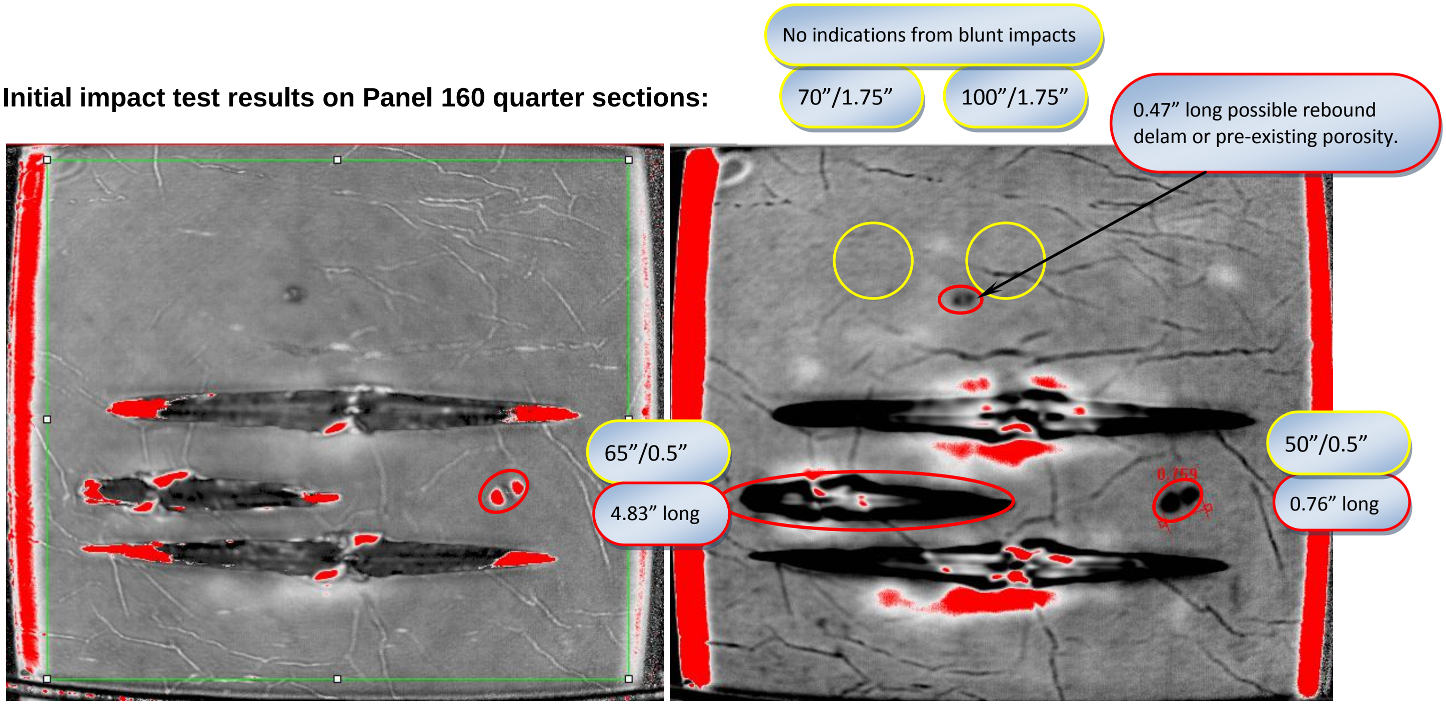


Figure 213. Thermography Post-impact Tegris 3M VHB *adhered* top-right quarter Panel 160. (Peak Ampl.- Pos. 2nd Deriv. & 1st Deriv. - 0.94 sec).

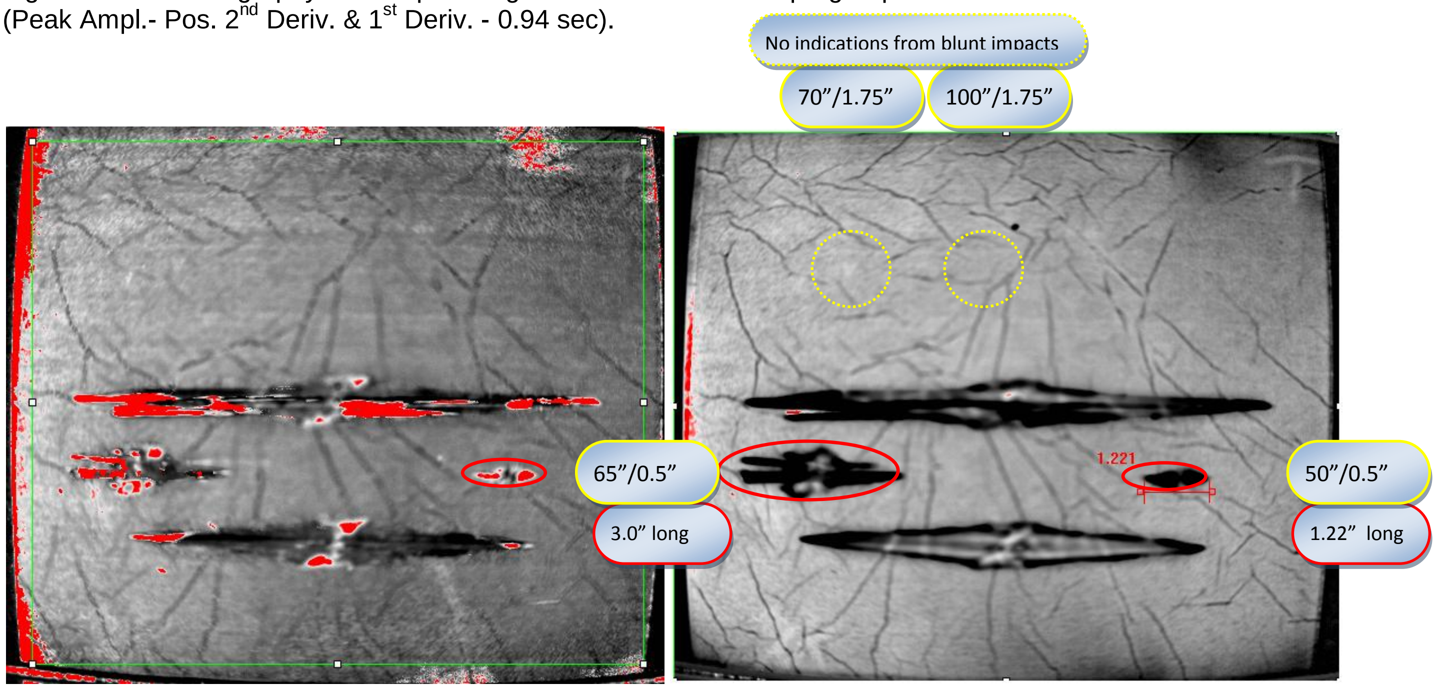


Figure 214a. Thermography Post-impact Tegris 3M VHB *w/backing paper* top-left quarter Panel 160 (Peak Ampl.- Pos. 2nd Deriv. & 1st Deriv. - 0.94 sec).

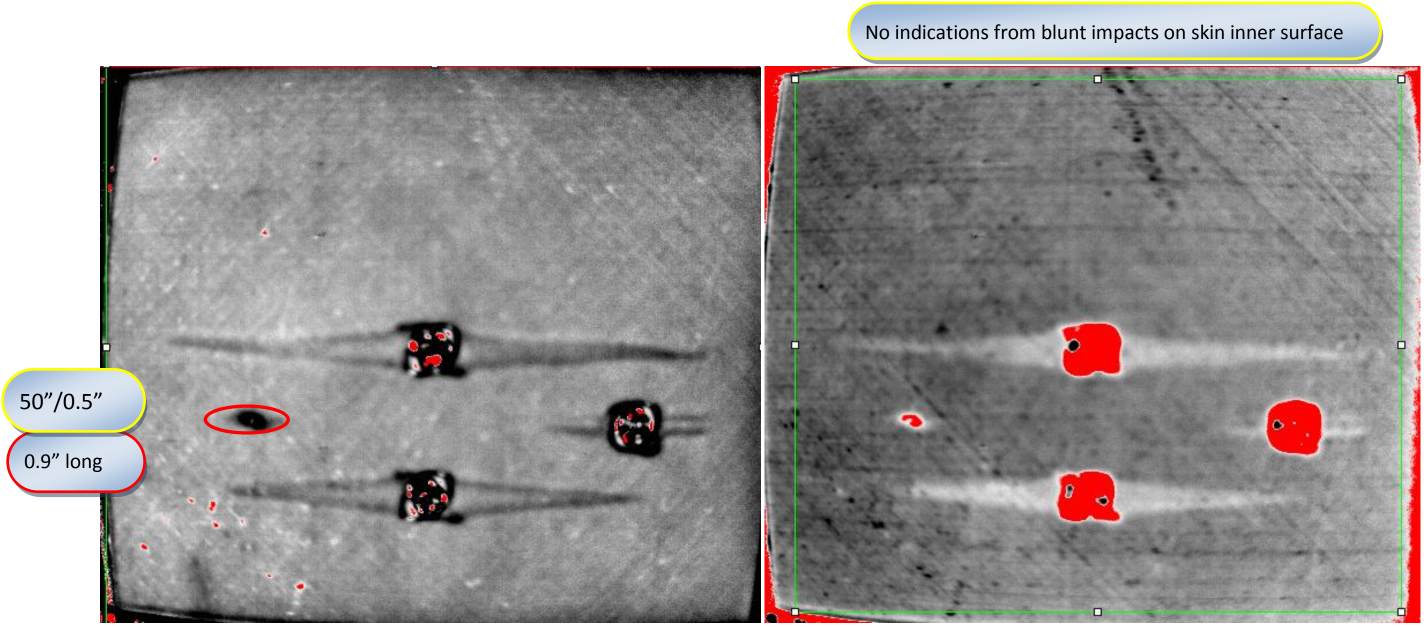


Figure 214b. Thermography Post-impact Tegris 3M VHB *w/backing paper* top-left quarter Panel 160 <inner tool-side mirror of figure above> (Peak Ampl.- Pos. 2nd Deriv. & 1st Deriv. - 0.3 sec)

Protection layer adhered to the substrate doesn’t seem to pose any problems for thermography sensitivity or interpretation as long as it is uniform. However, in subsequent panels with 3M backing paper intact it was found that the varying degree of contact due to the protective layer impact damage, did leave artifacts in the IRT image of an undamaged laminate.

As is often the case, impact delamination is larger on the backside (bag-side), shown as 1.22” long in Fig. 214a, compared to 0.9” long near-surface laminate IR image in Fig. 214b.

It is thought the variation in impact damage extent with 3M VHB backing paper in-place vs. removed & adhered has more to do with variation in the UNI porosity mophology between these panels & laminate quality, than influence of the protective layer adherence. It was also noted that the delaminations continued to grow hours after the impact due to residual stresses at the impacted surface with this UNI laminate material.

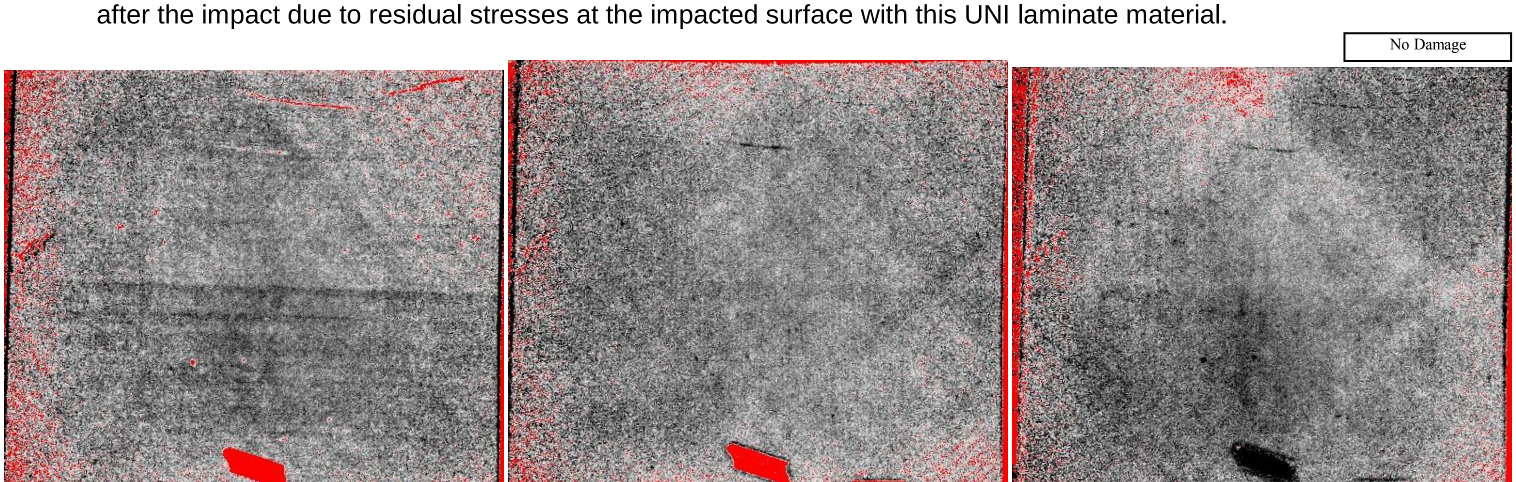


Figure 215. Post-Strike Thermography Back Panel 161 {LS-45} (1st Deriv. – 0.08s, 0.42s, 0.94s)

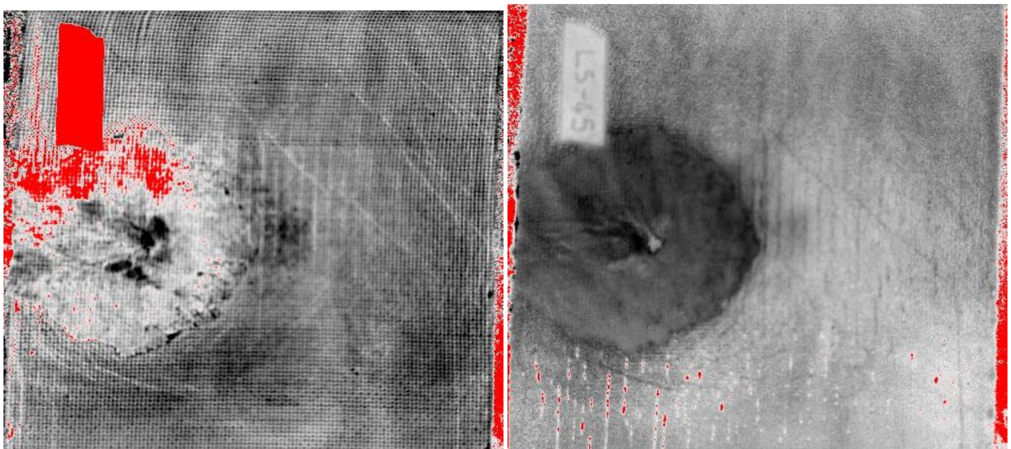


Figure 216. Post-Strike Thermography Front Panel 161 {LS-45} (1st Deriv. – 0.4s & 8.66s)

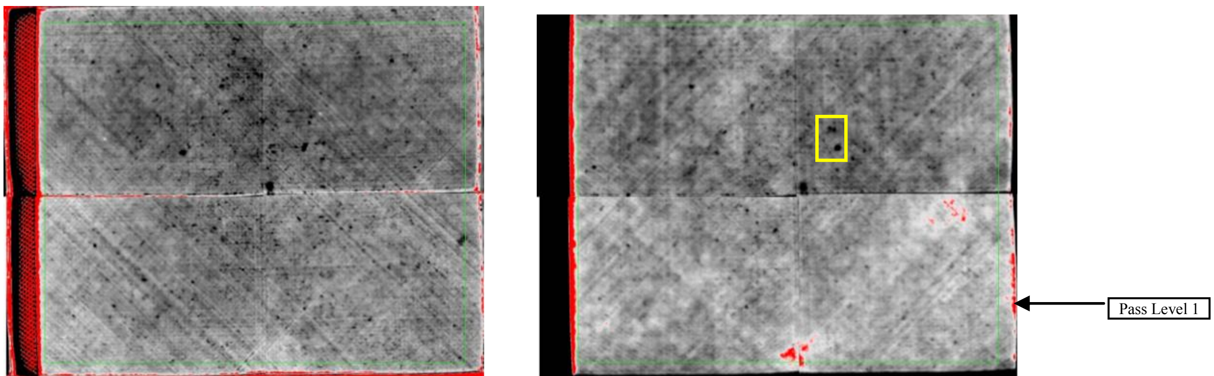


Figure 217. Thermography AS162 (1st Deriv. - 0.42 & 0.94 sec)

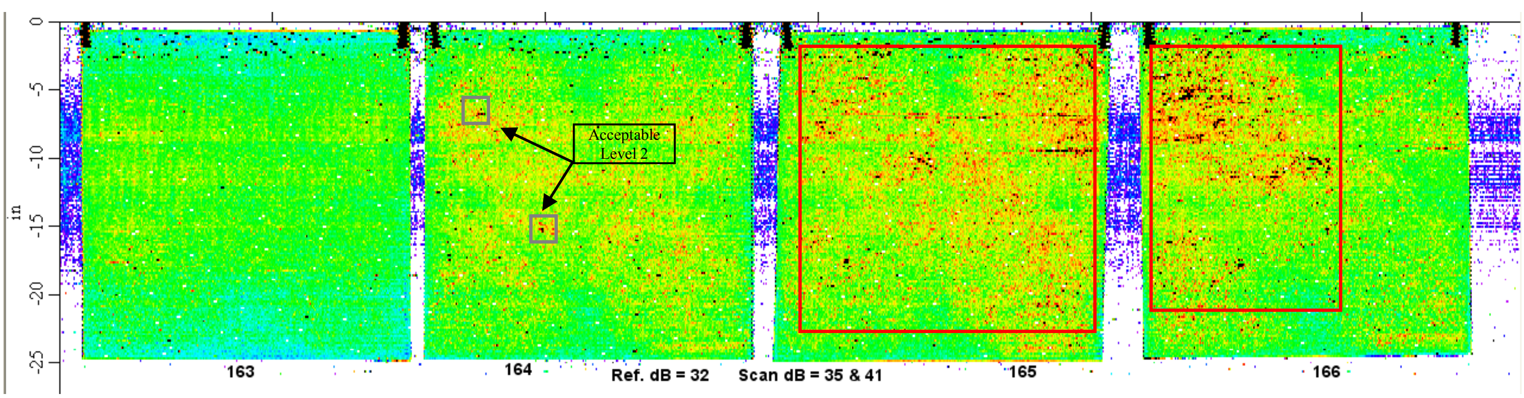


Figure 218. 5 MHz TTU Panel 163, 164, 165, 166

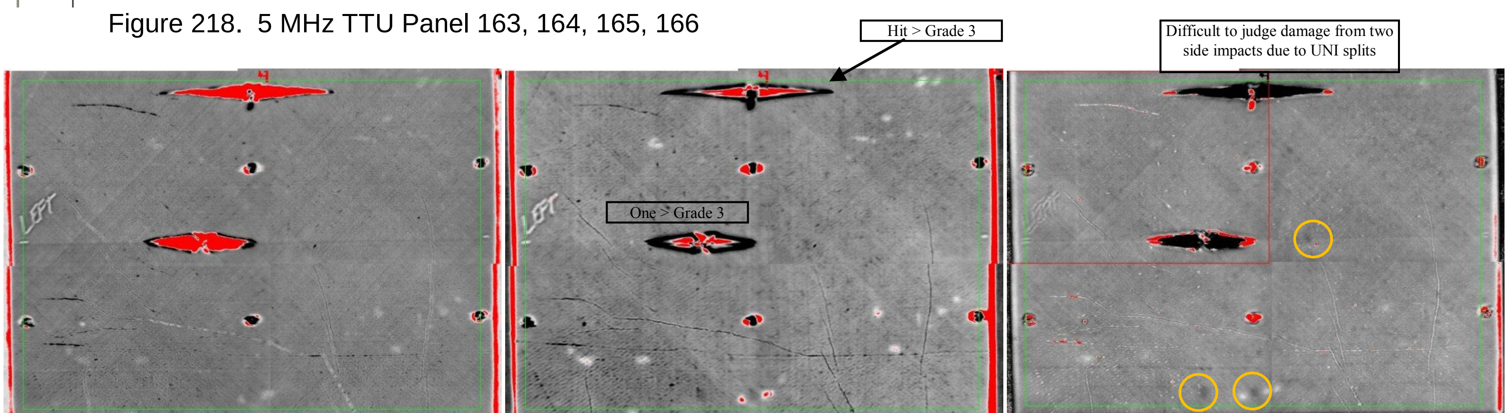


Figure 219. Post-Impact Thermography adhered Panel 163 {IM-100} (1st Deriv. - 0.42, 0.94s & Peak Ampl)

Artifacts from contact by coating layer damage
- No PEUT loss in bottom center indication

No Apparent Damage – porosity is high in region of interest (Fails Level 2)

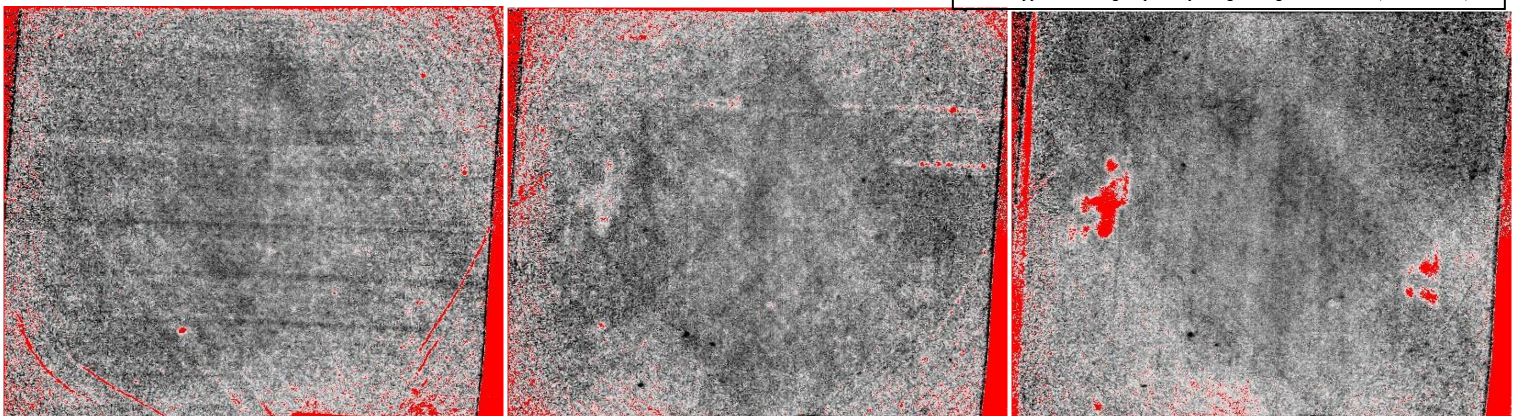


Figure 220. Post-Strike Thermography Back Panel 165 {LS-4} (1st Deriv. – 0.08s, 0.42s, 0.94s)

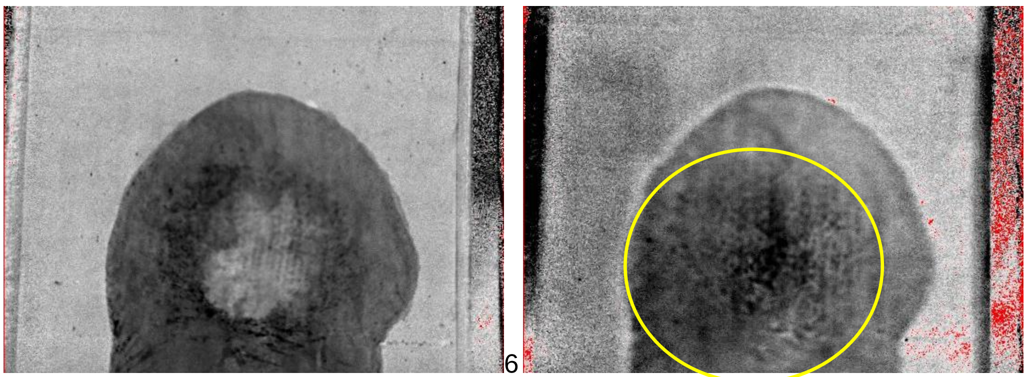
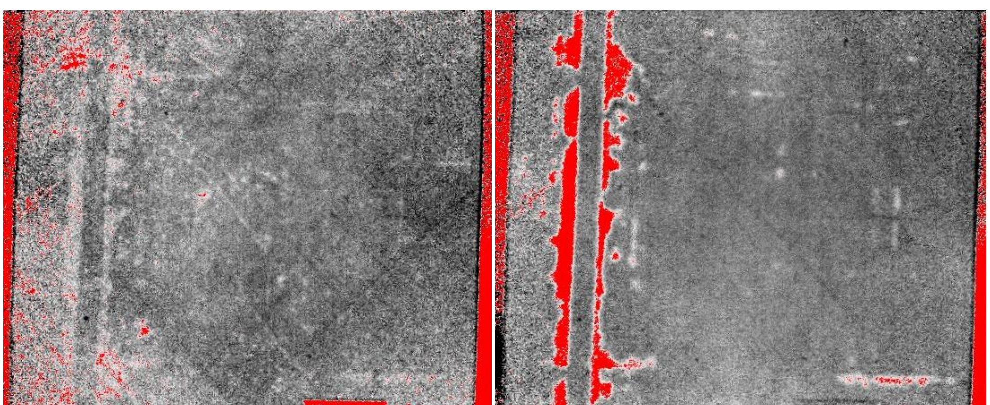


Figure 221. Post-Strike Thermography Front Panel 165 {LS-4} (1st Deriv. – 0.4s & 8.66s)



No Apparent Damage – porosity is high in region of interest (Fails Level 2)

Figure 222. Post-Strike Thermography Back Panel 166 {LS-10} (1st Deriv. – 0.08s, 0.42s, 0.94s)

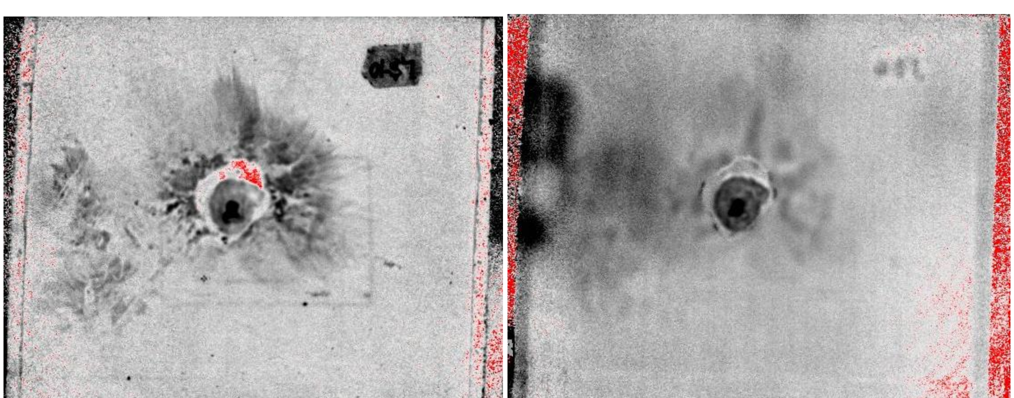


Figure 223. Post-Strike Thermography Front Panel 166 {LS-10} (1st Deriv. – 0.4s & 8.66s)

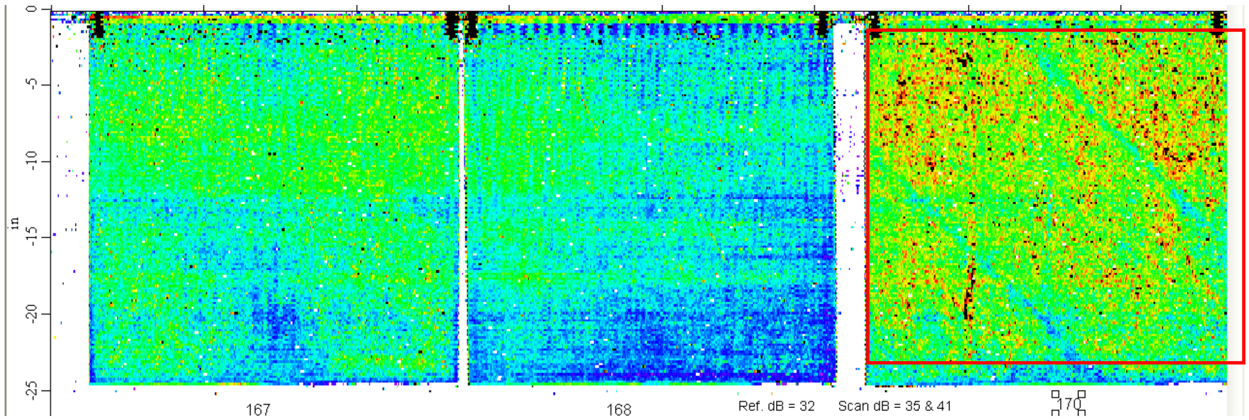


Figure 224. 5 MHz TTU Panel 167, 168, 170

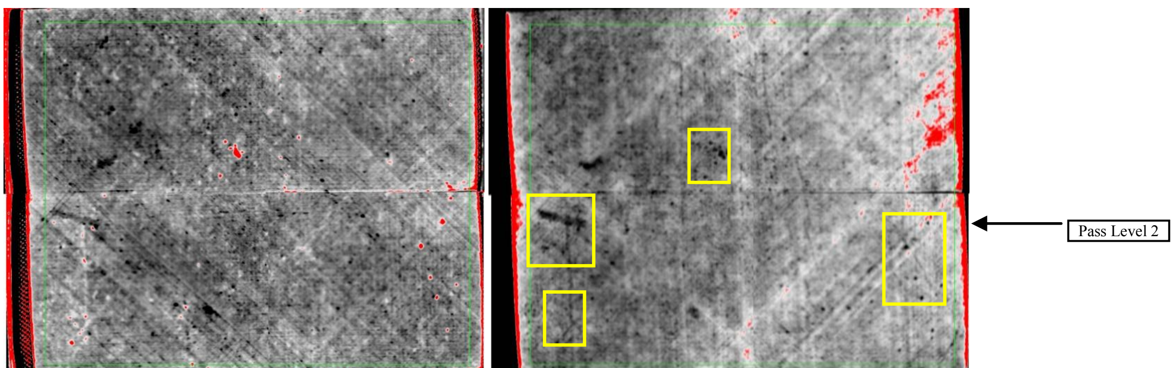


Figure 225. Thermography AS169 (1st Deriv. - 0.42 & 0.94 sec)

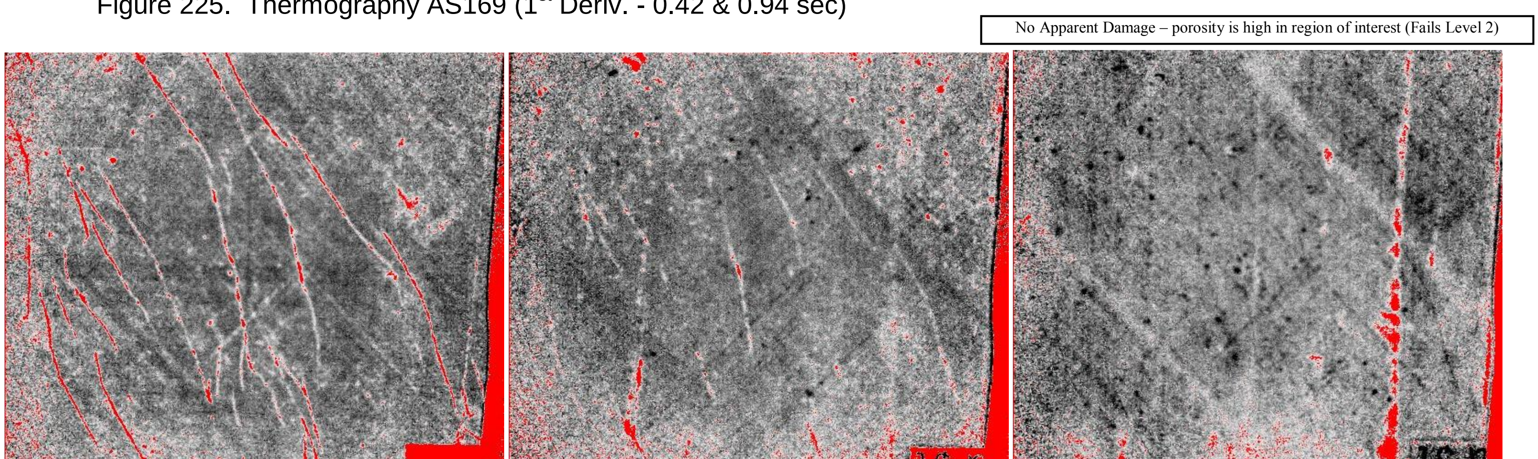


Figure 226. Post-Strike Thermography Back Panel 170 {LS-12} (1st Deriv. – 0.08s, 0.42s, 0.94s)

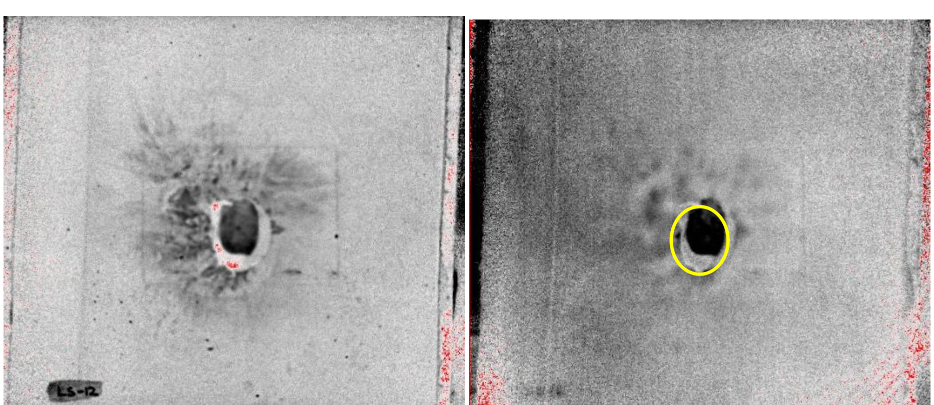


Figure 227. Post-Strike Thermography Front Panel 170 {LS-12} (1st Deriv. – 0.4s & 8.66s)

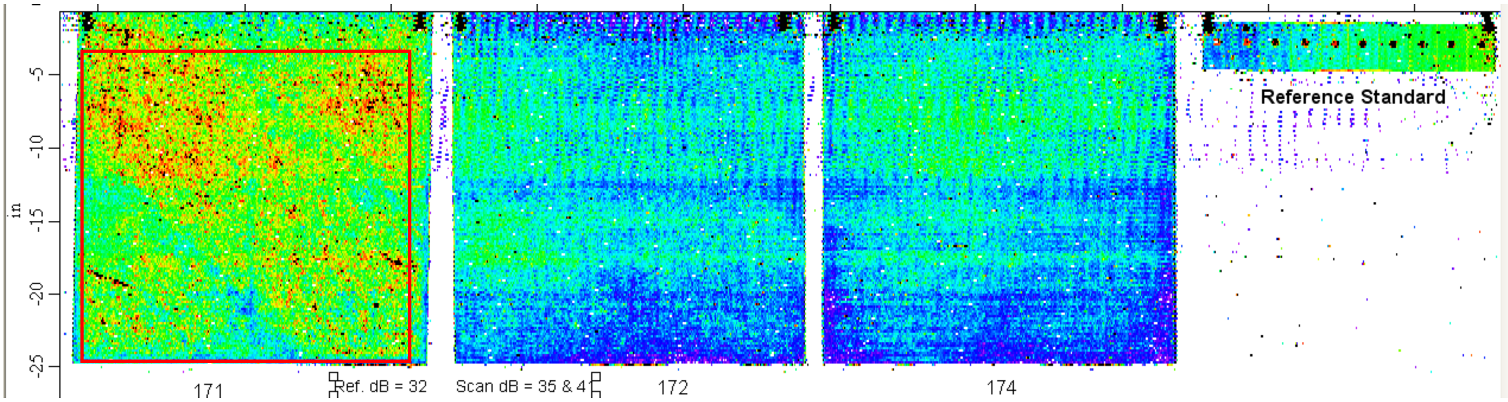


Figure 228. 5 MHz TTU Panel 171, 172, 173

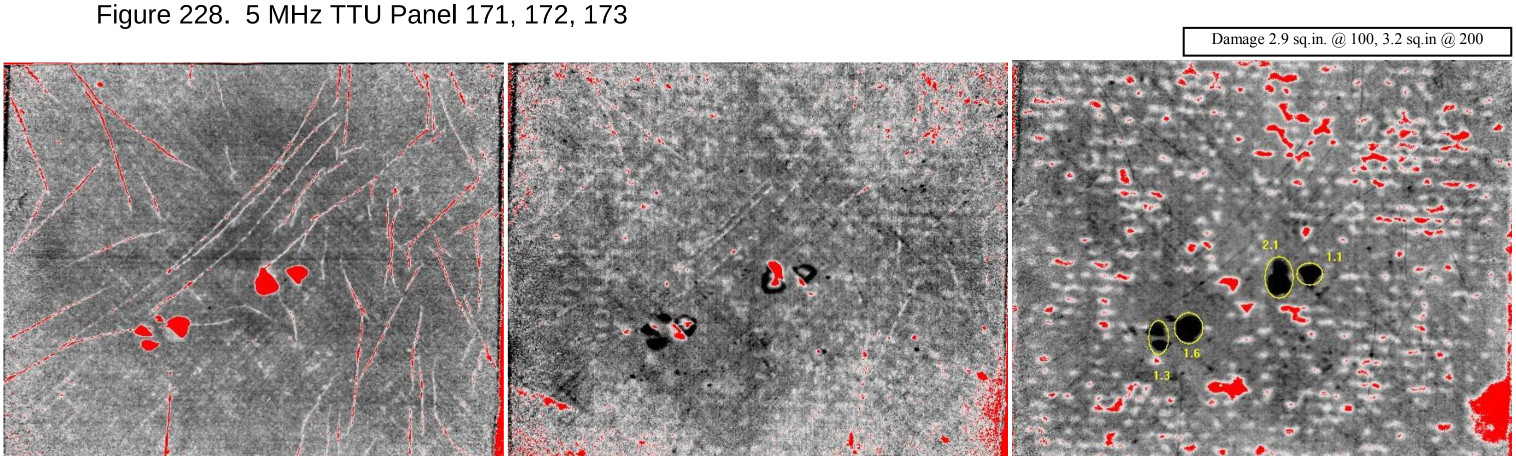


Figure 229. Post-Strike Thermography Back Panel 171 {LS-40} (1st Deriv. – 0.08s, 0.42s, 0.94s)

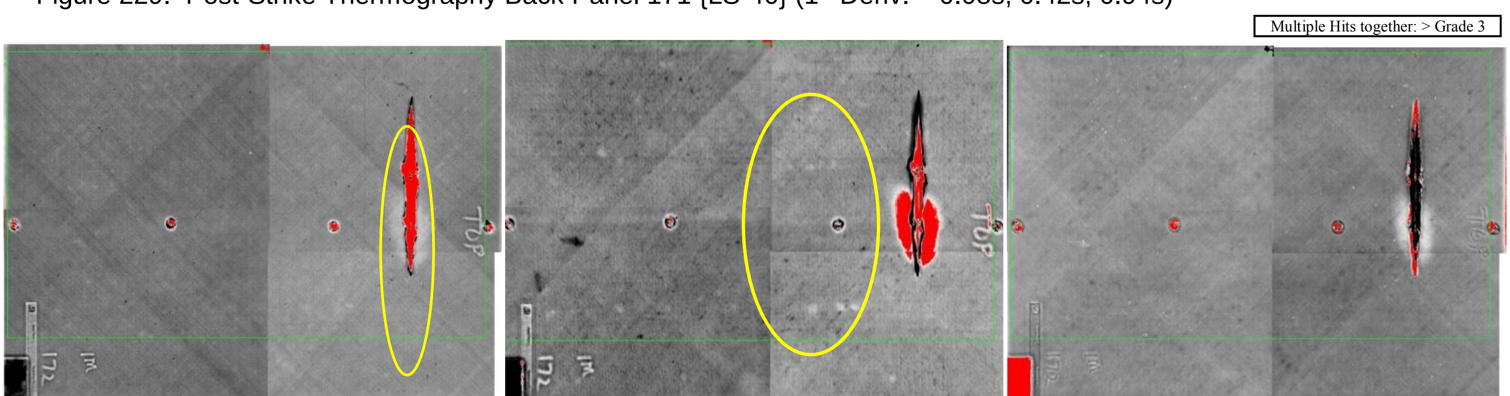


Figure 230. Post-Impact Thermography Panel 172 {IM-57} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

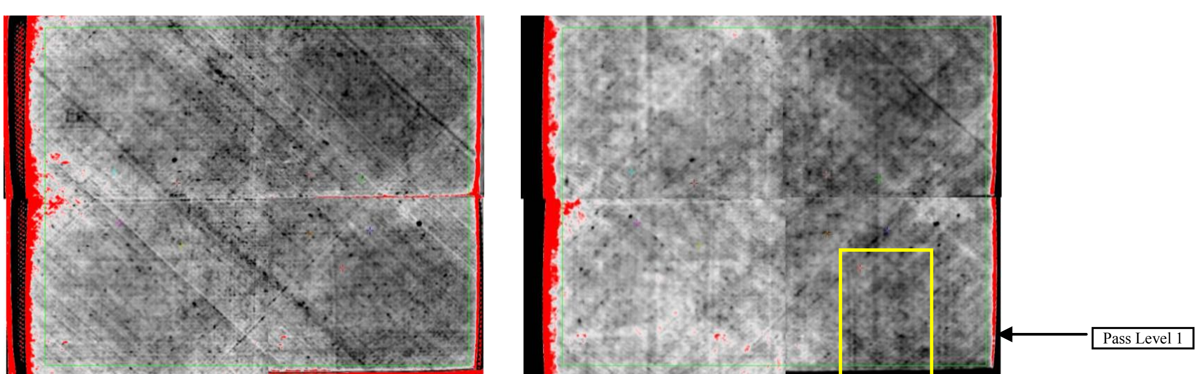


Figure 231. Thermography AS173 (1st Deriv. - 0.42 & 0.94 sec)

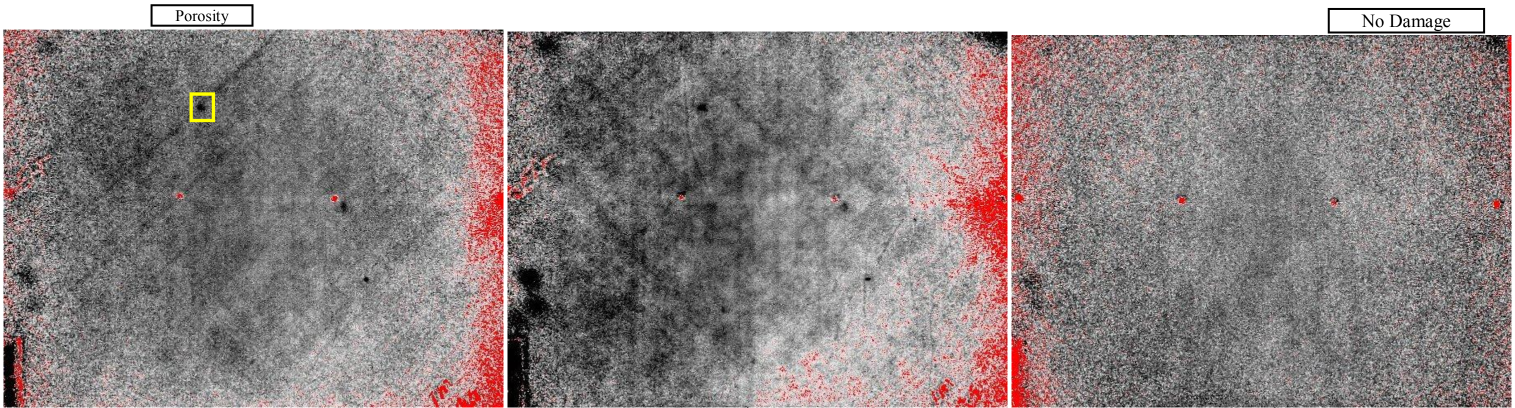


Figure 232. Post-Impact Thermography Panel 173 {IM-36} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

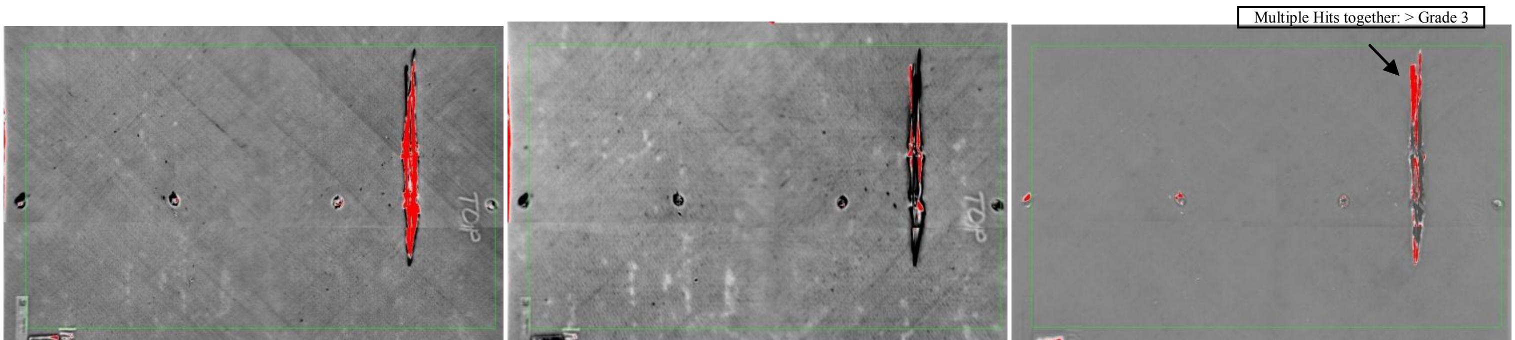


Figure 233. Post-Impact Thermography adhered Panel 174 {IM-47} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

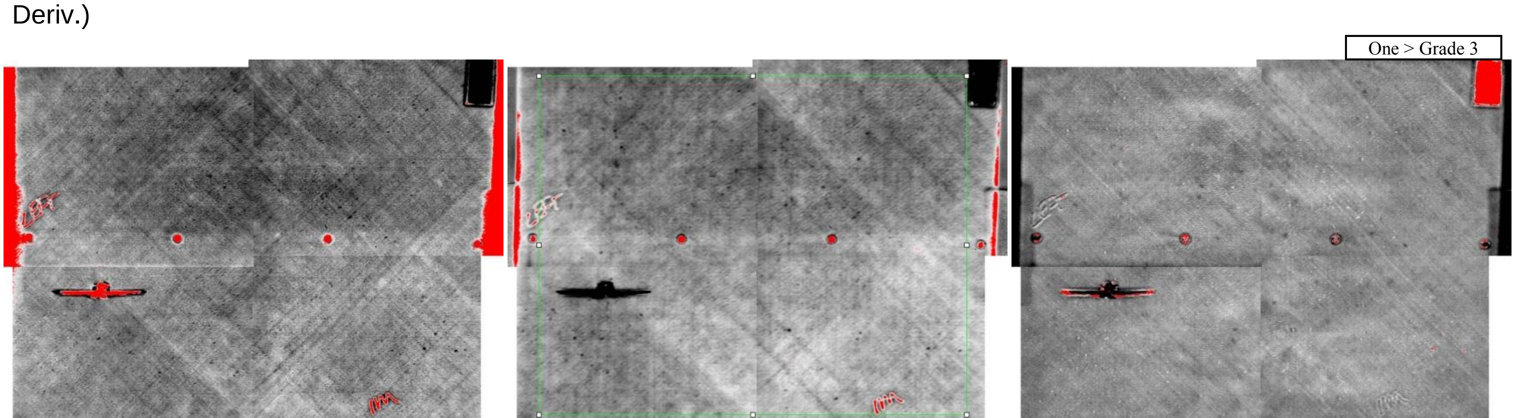


Figure 234. Post-Impact Thermography Panel 175 {IM-7} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

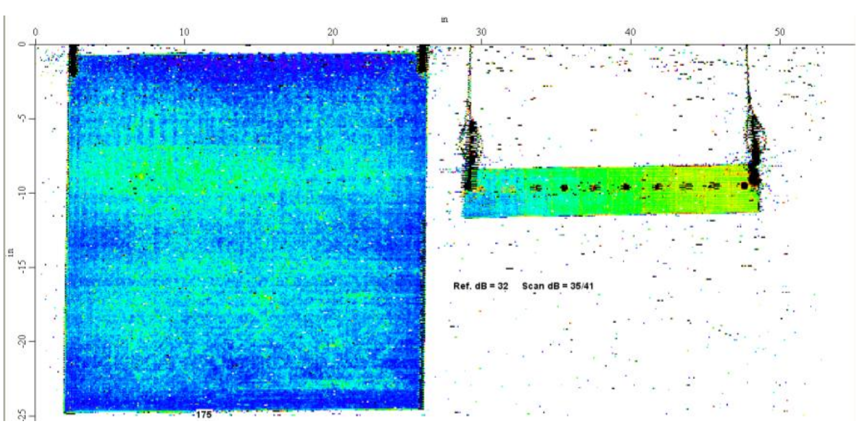


Figure 235. 5 MHz TTU Panel 175

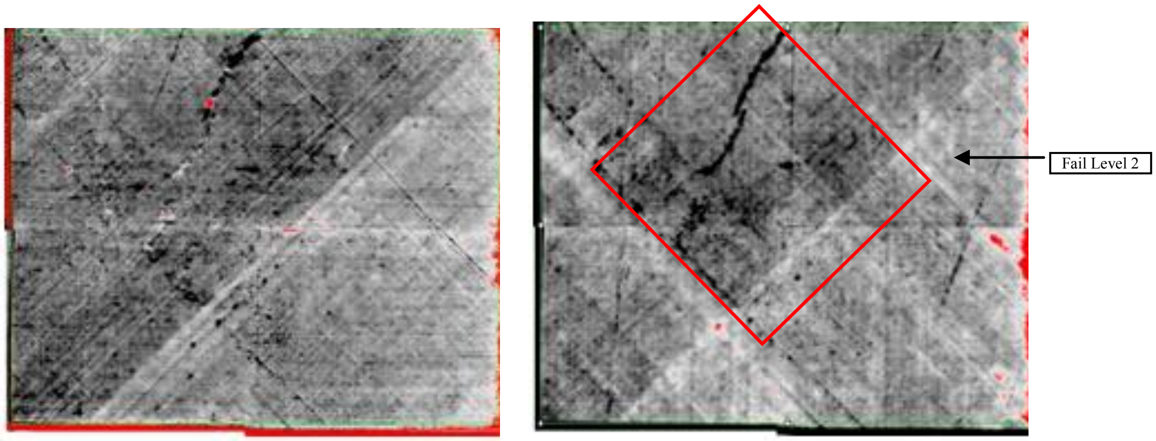


Figure 236. Thermography AS176 (1st Deriv. - 0.42 & 0.94 sec)

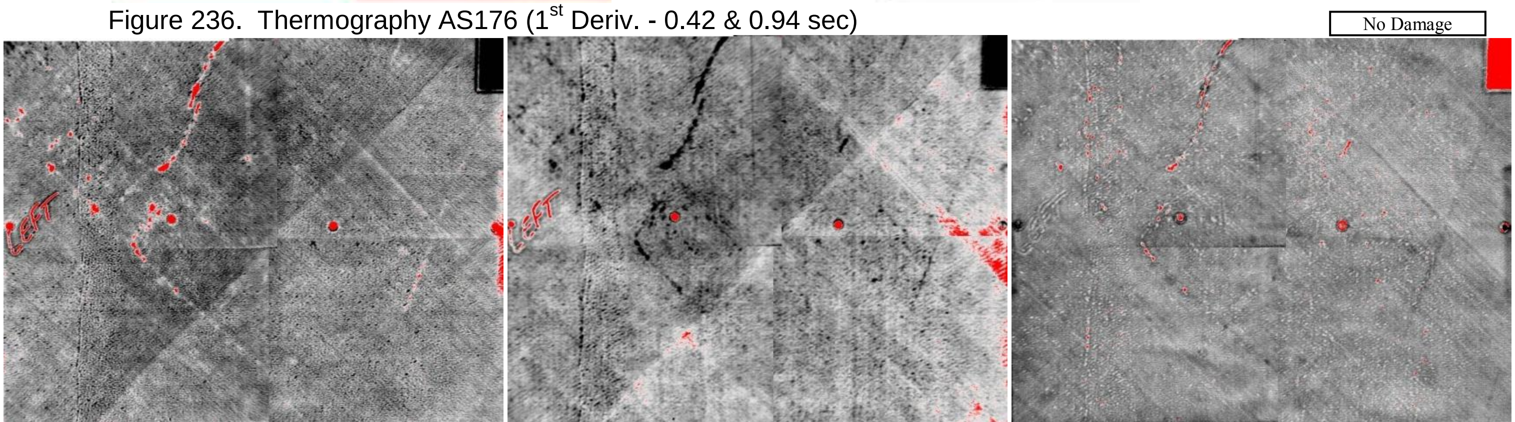


Figure 237. Post-Impact Thermography Panel 176 {IM-25} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

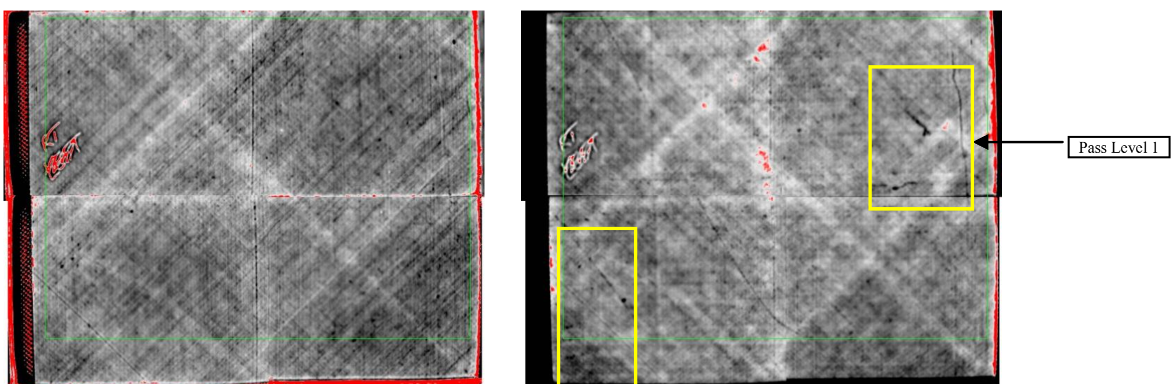


Figure 238. Thermography AS177 (1st Deriv. - 0.42 & 0.94 sec)

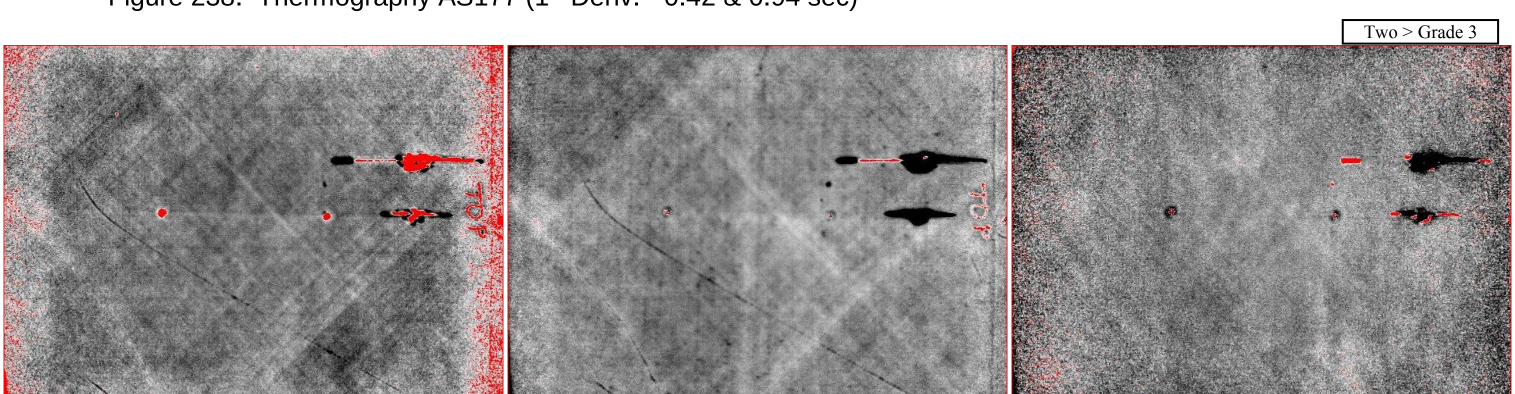


Figure 239. Post-Impact Thermography Panel 177 {IM-76} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

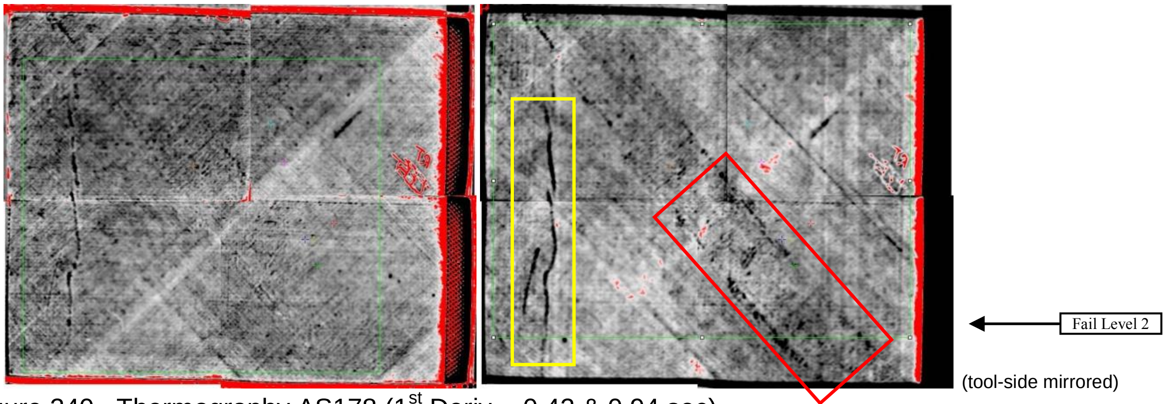


Figure 240. Thermography AS178 (1st Deriv. - 0.42 & 0.94 sec)

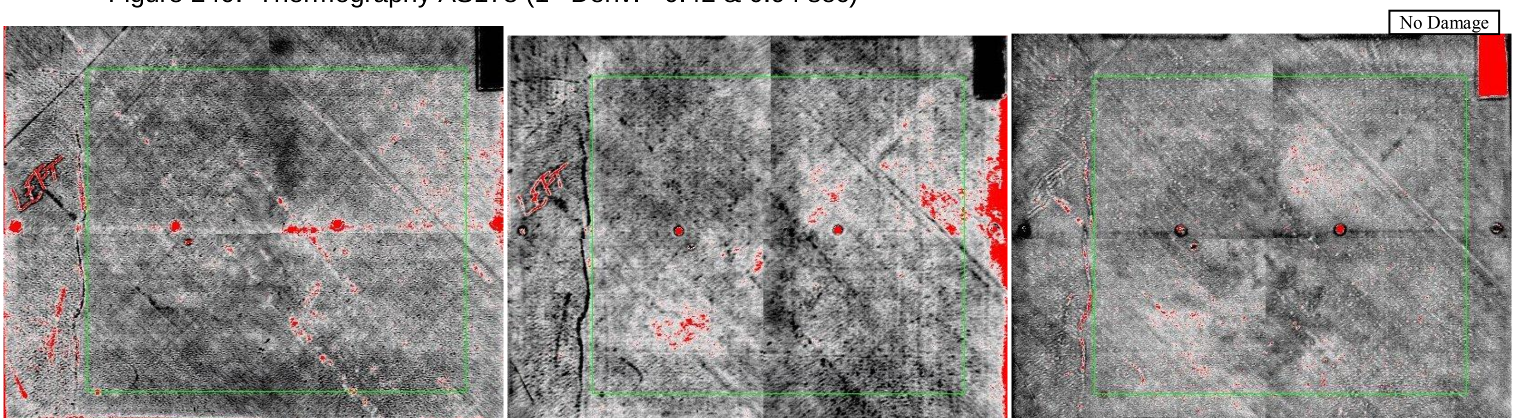


Figure 240. Post-Impact Thermography Panel 178 {IM-26} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

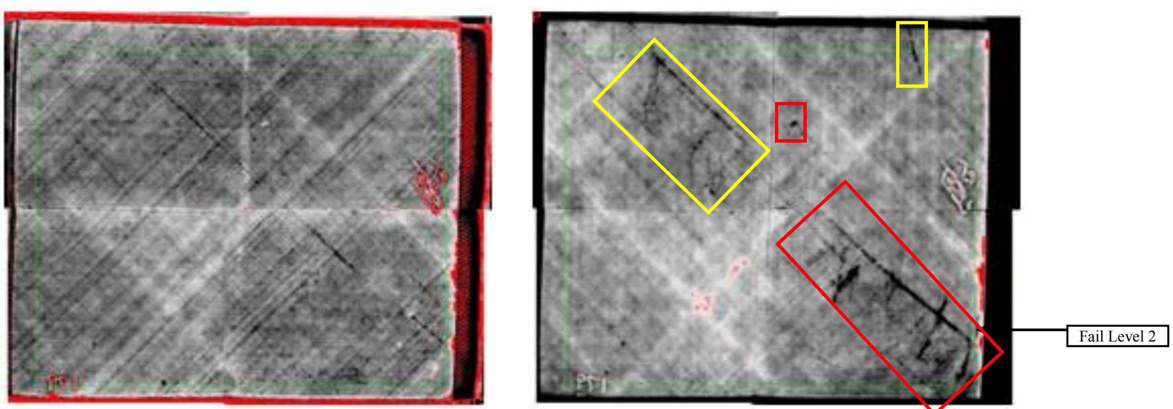


Figure 241. Thermography AS179 (1st Deriv. - 0.42 & 0.94 sec)

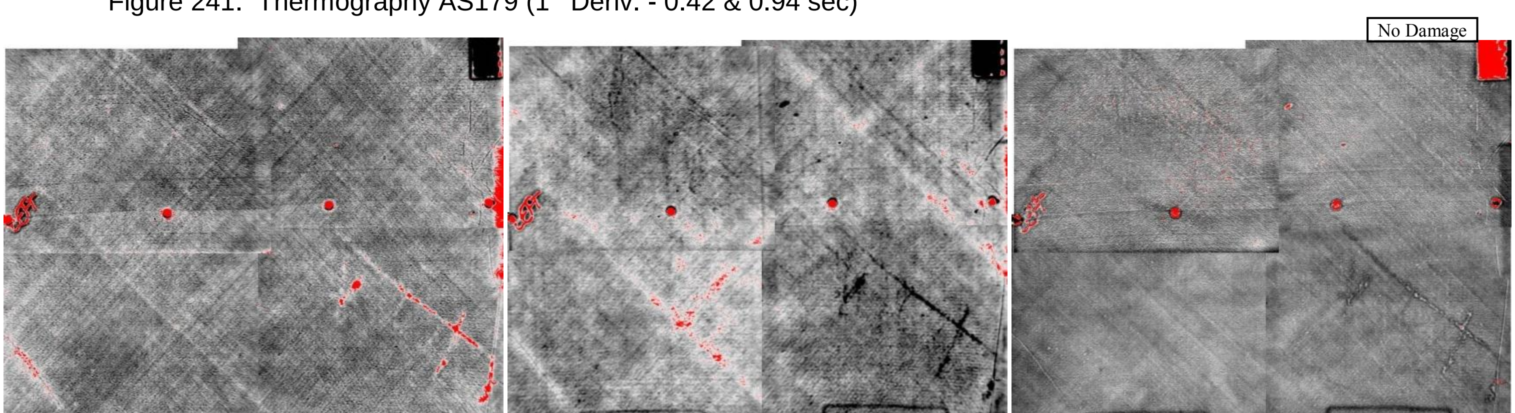


Figure 242. Post-Impact Thermography Panel 179 {IM-16} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

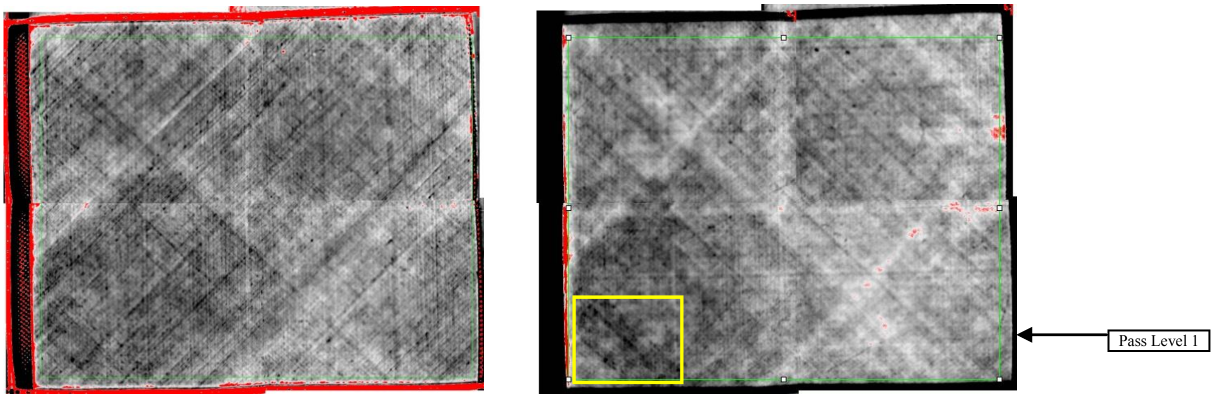


Figure 243. Thermography AS180 (1st Deriv. - 0.42 & 0.94 sec)

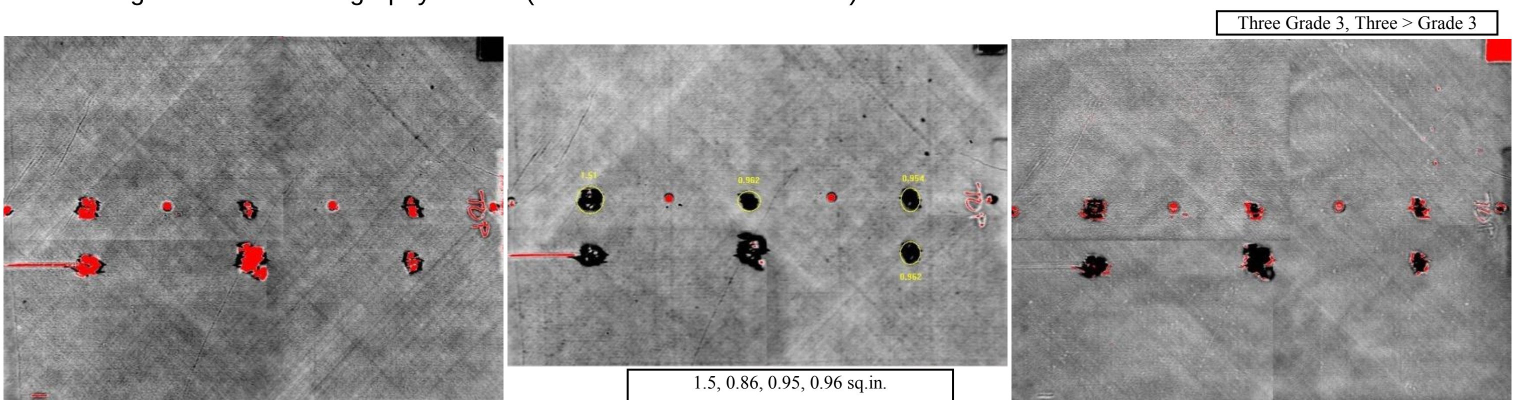


Figure 244. Post-Impact Thermography Panel 180 {IM-87} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

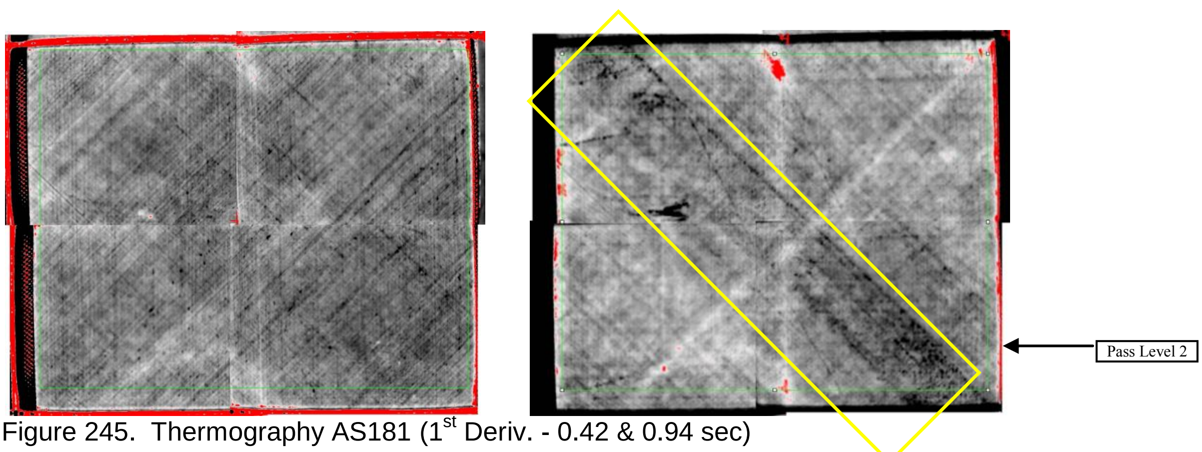


Figure 245. Thermography AS181 (1st Deriv. - 0.42 & 0.94 sec)

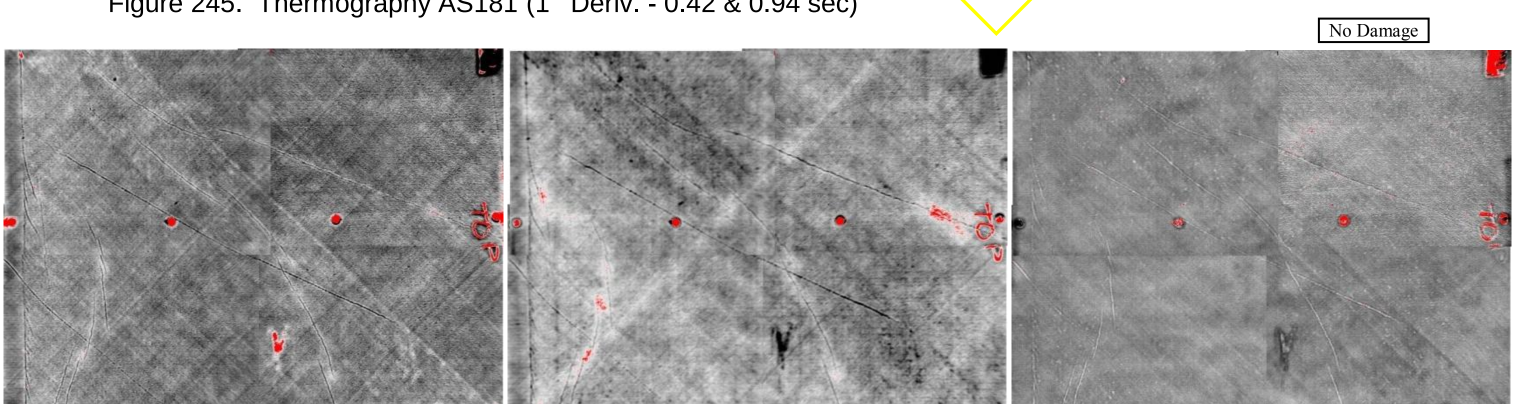


Figure 246. Post-Impact Thermography Panel 181 {IM-23} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

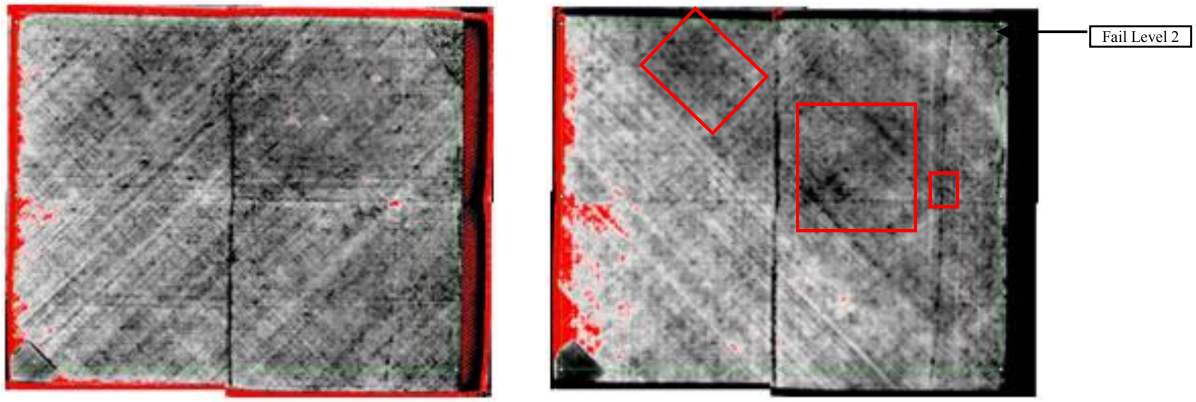


Figure 247. Thermography AS182 (1st Deriv. - 0.42 & 0.94 sec)

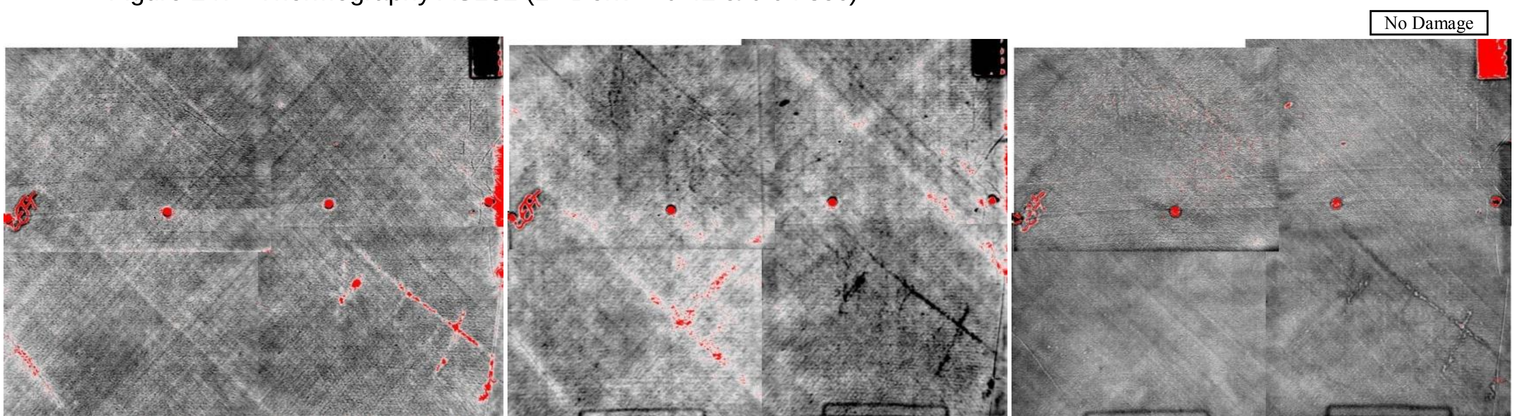


Figure 248. Post-Impact Thermography Panel 182 {IM-34} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

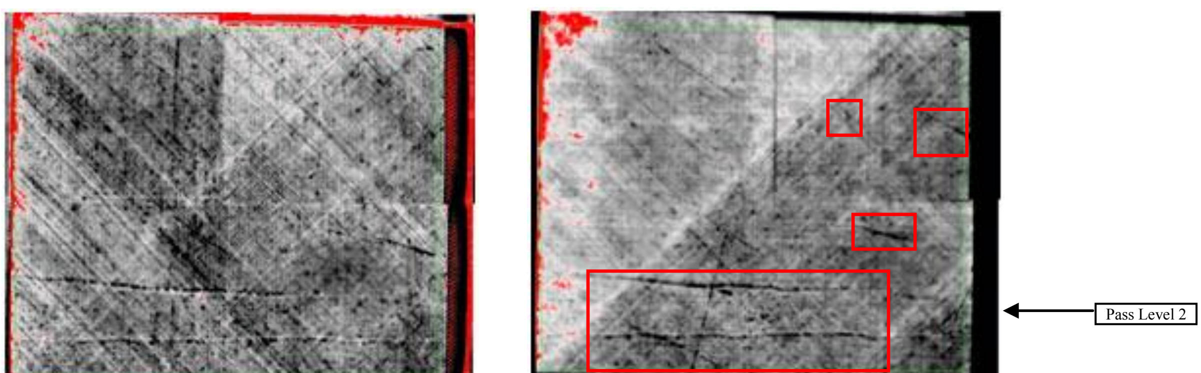


Figure 249. Thermography AS183 (1st Deriv. - 0.42 & 0.94 sec)

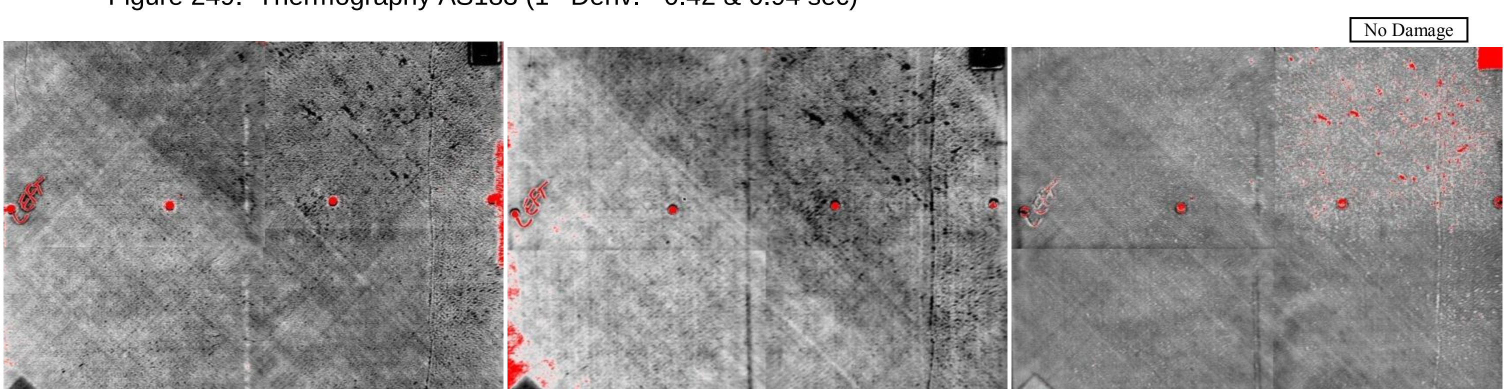


Figure 250. Post-Impact Thermography Panel 183 {IM-35} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

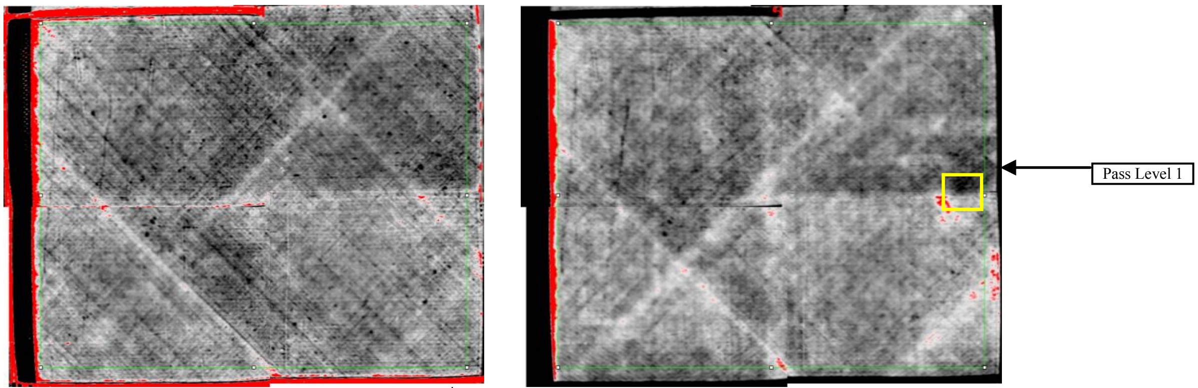


Figure 251. Thermography AS184 (1st Deriv. - 0.42 & 0.94 sec)

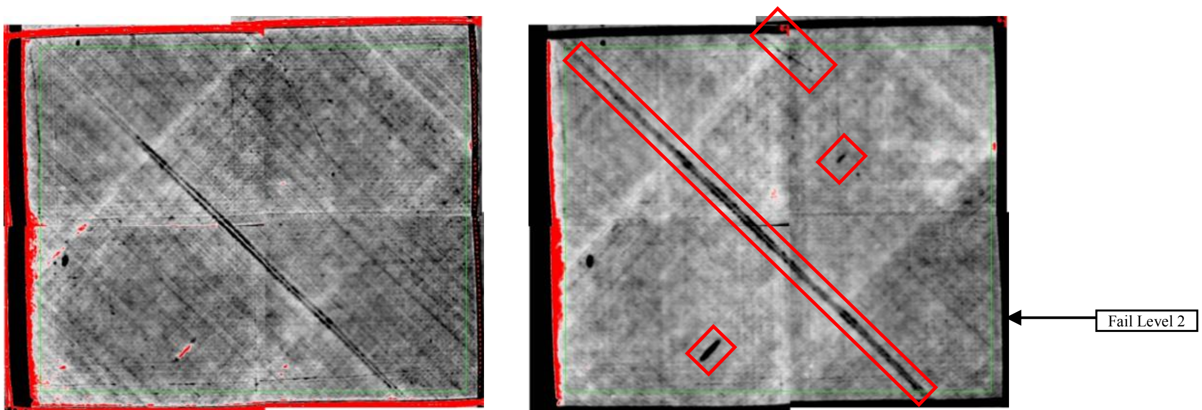


Figure 252. Thermography AS185 (1st Deriv. - 0.42 & 0.94 sec)

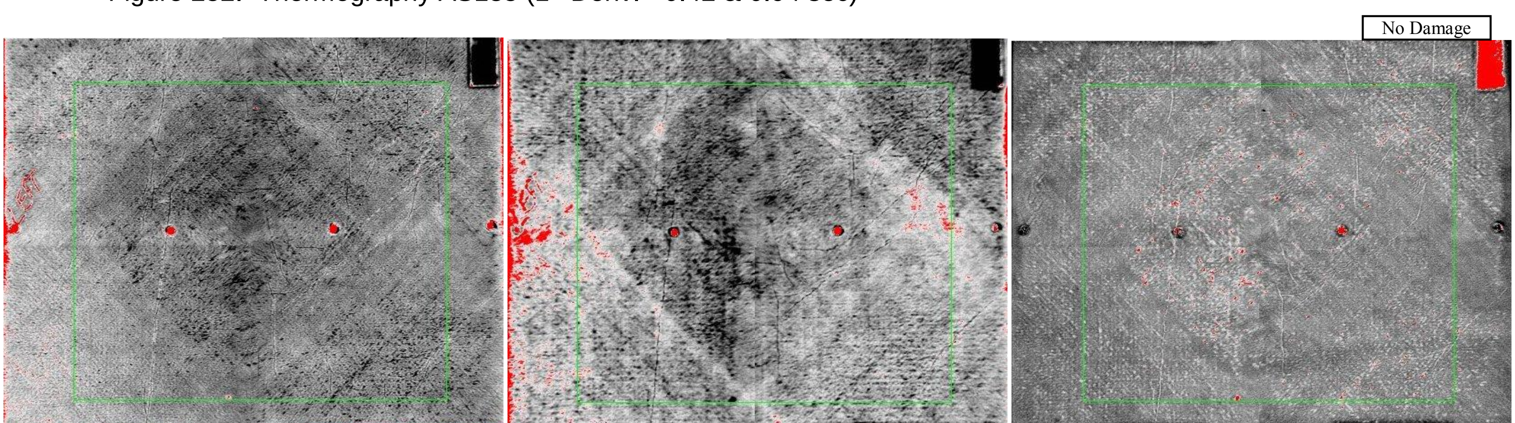


Figure 253. Post-Impact Thermography Panel 185 {IM-85} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

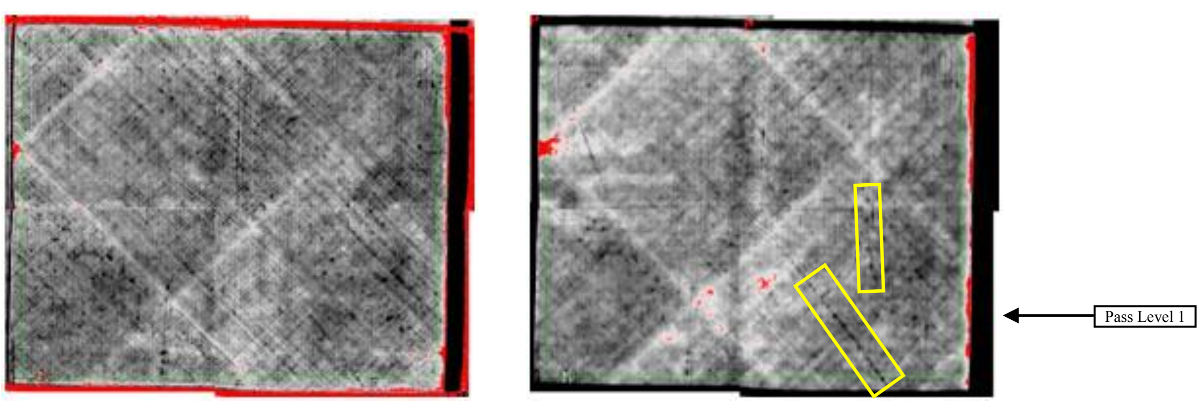


Figure 254. Thermography AS186 (1st Deriv. - 0.42 & 0.94 sec)

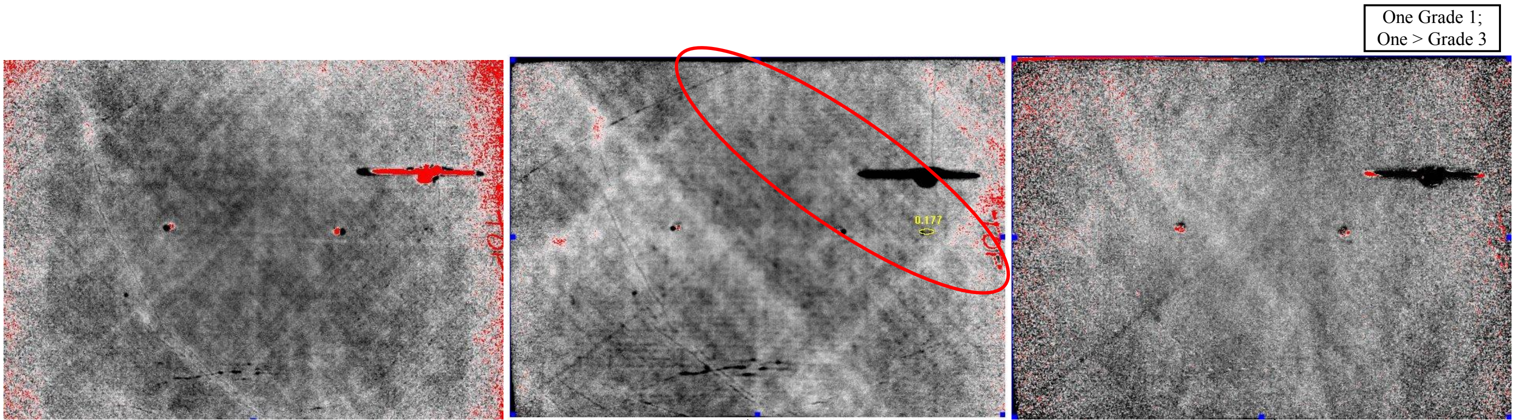


Figure 255. Post-Impact Thermography Panel 186 {IM-74} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

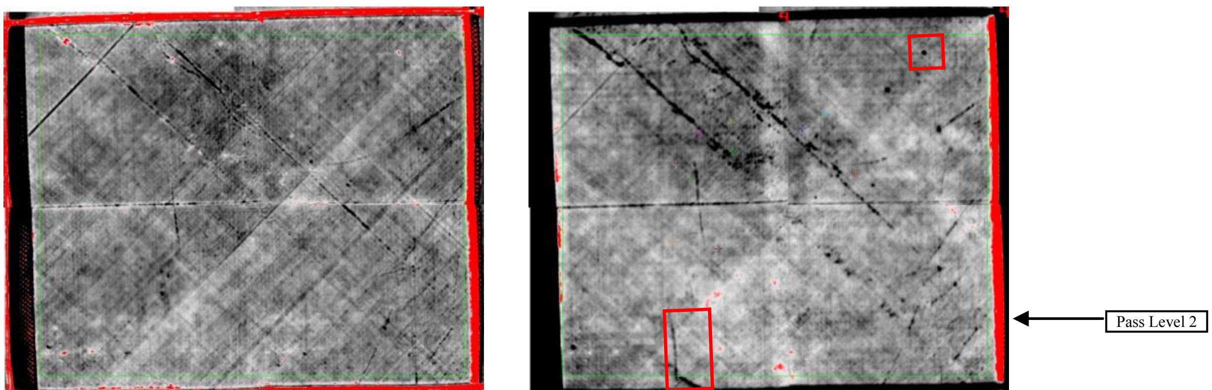


Figure 256. Thermography AS187 (1st Deriv. - 0.42 & 0.94 sec)

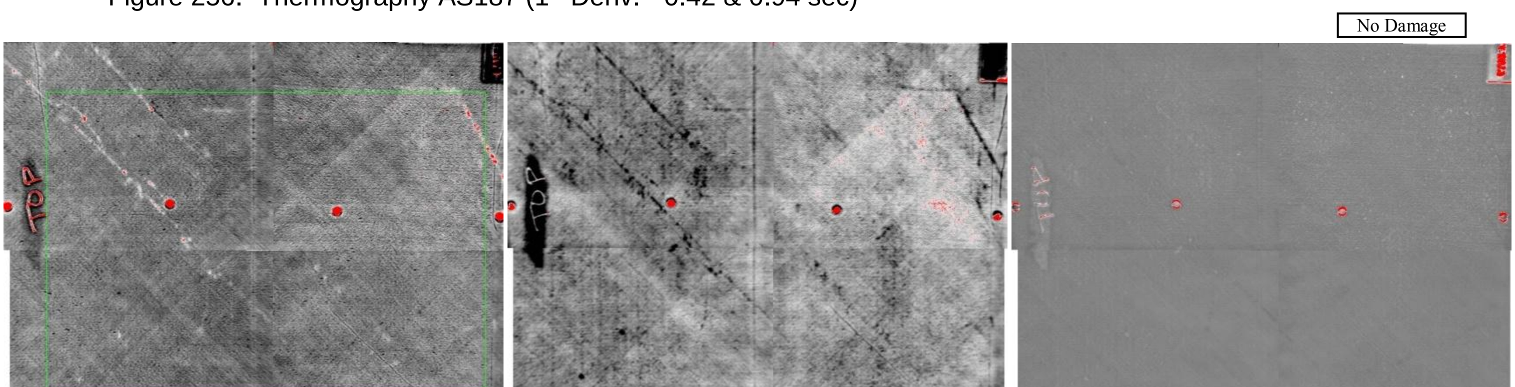


Figure 257. Post-Impact Thermography Panel 187 {IM-84} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

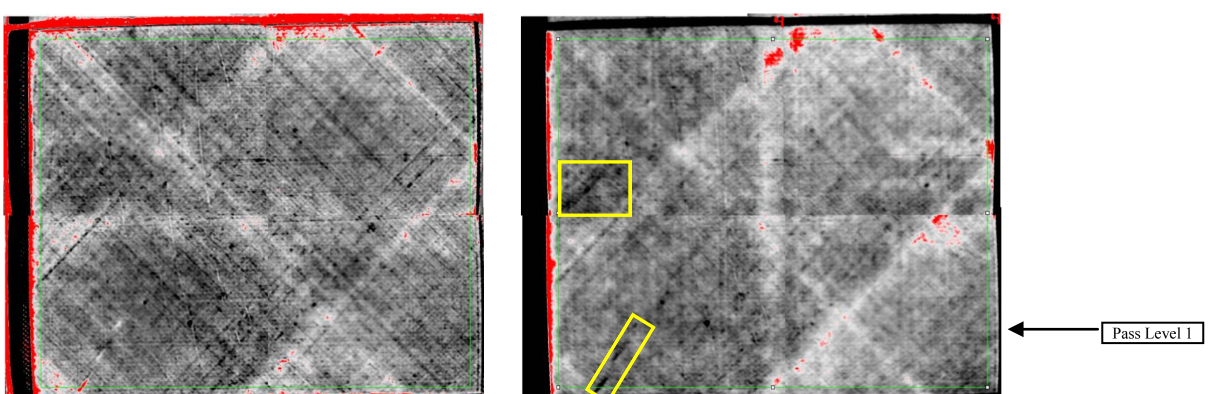


Figure 258. Thermography AS188 (1st Deriv. - 0.42 & 0.94 sec)

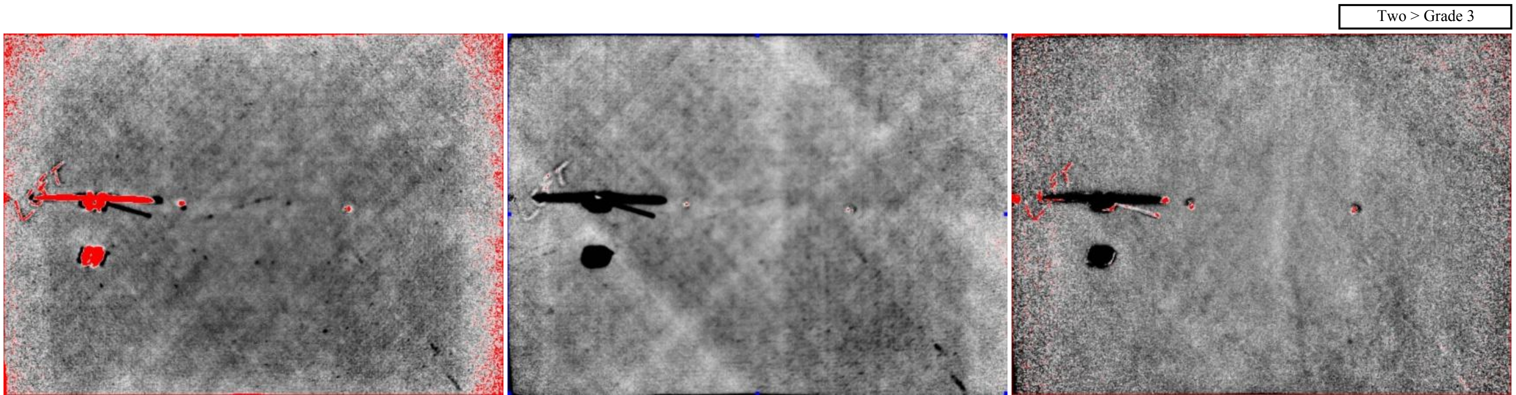


Figure 259. Post-Impact Thermography Panel 188 {IM-49} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

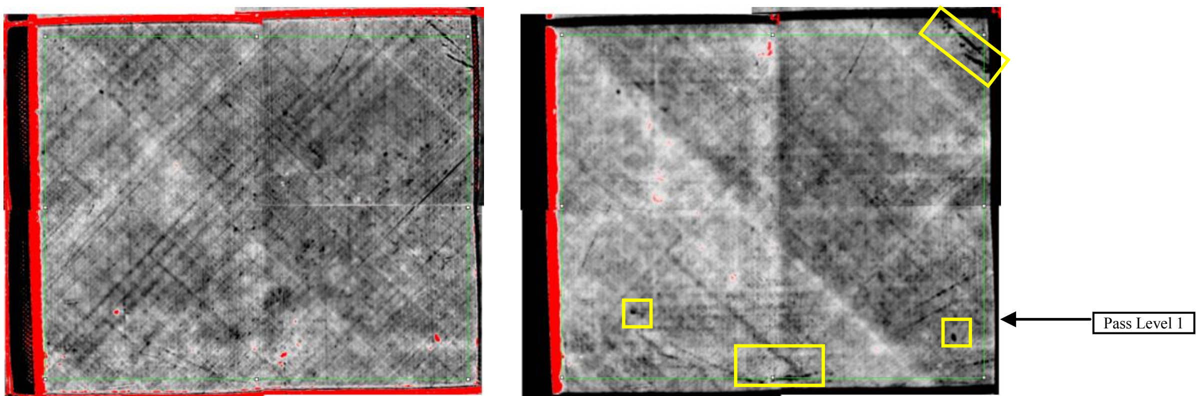


Figure 260. Thermography AS189 (1st Deriv. - 0.42 & 0.94 sec)

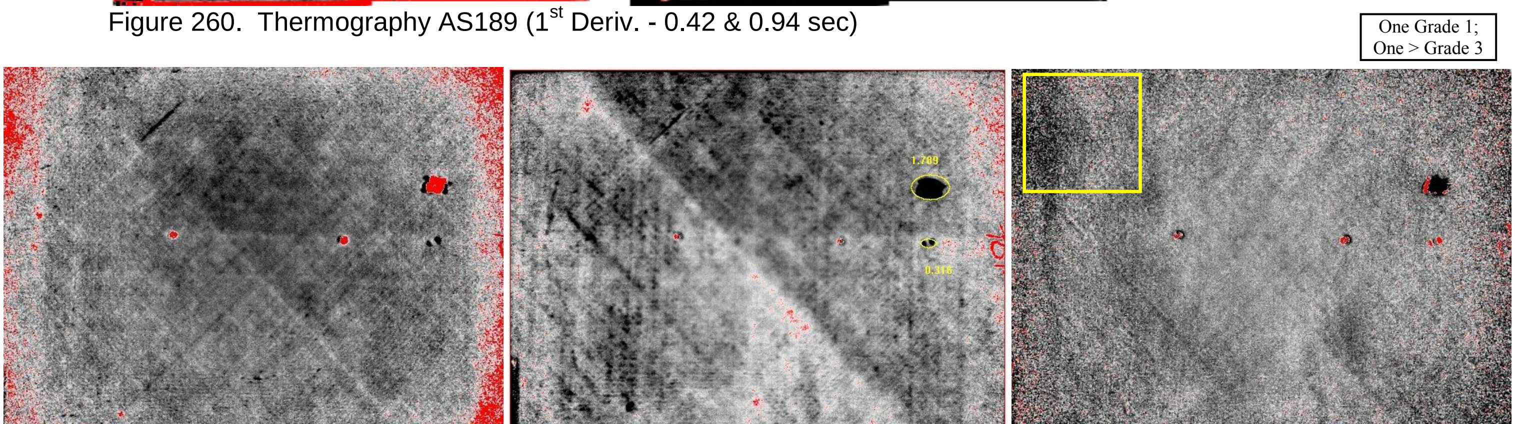


Figure 261. Post-Impact Thermography Panel 189 {IM-80} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

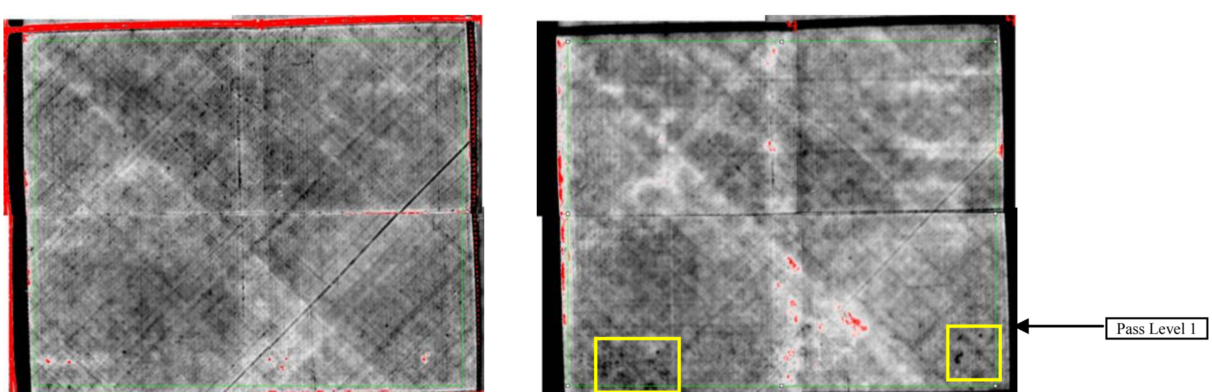


Figure 262. Thermography AS190 (1st Deriv. - 0.42 & 0.94 sec)

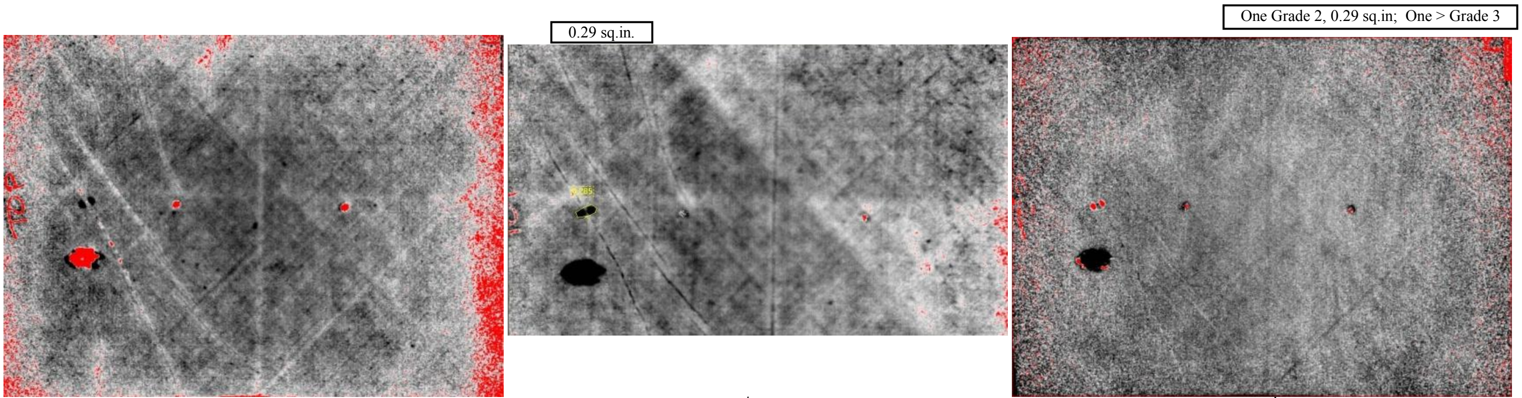


Figure 263. Post-Impact Thermography Panel 190 {IM-77} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

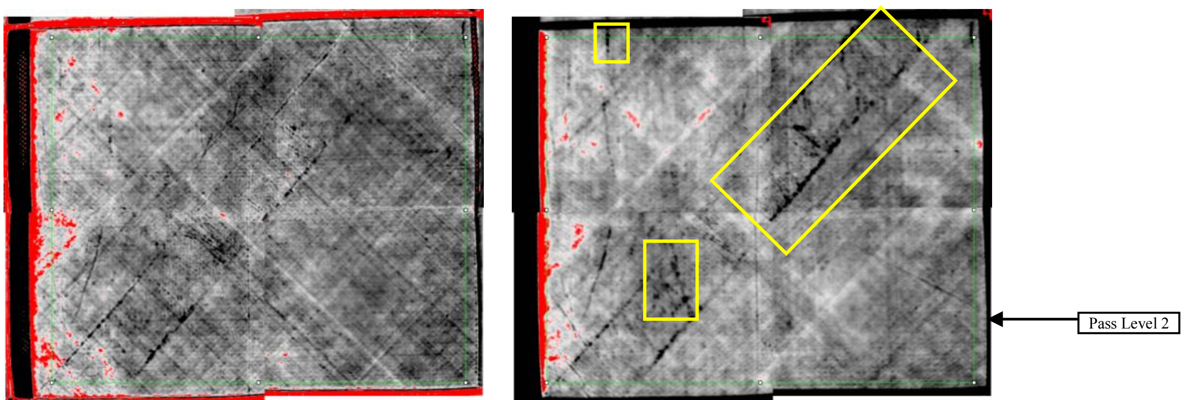


Figure 264. Thermography AS191 (1st Deriv. - 0.42 & 0.94 sec)

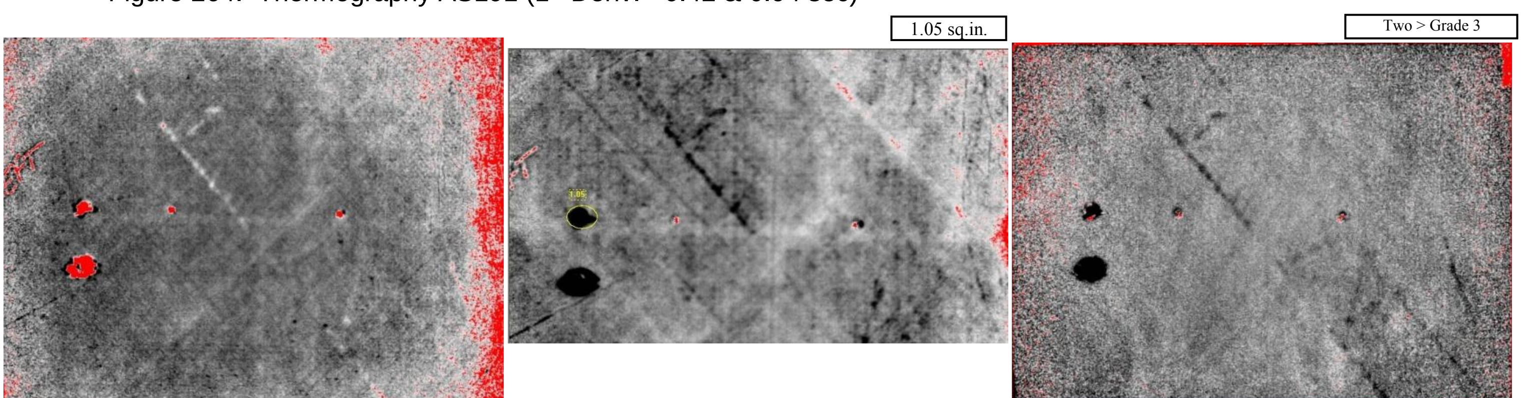


Figure 265. Post-Impact Thermography Panel 191 {IM-5} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

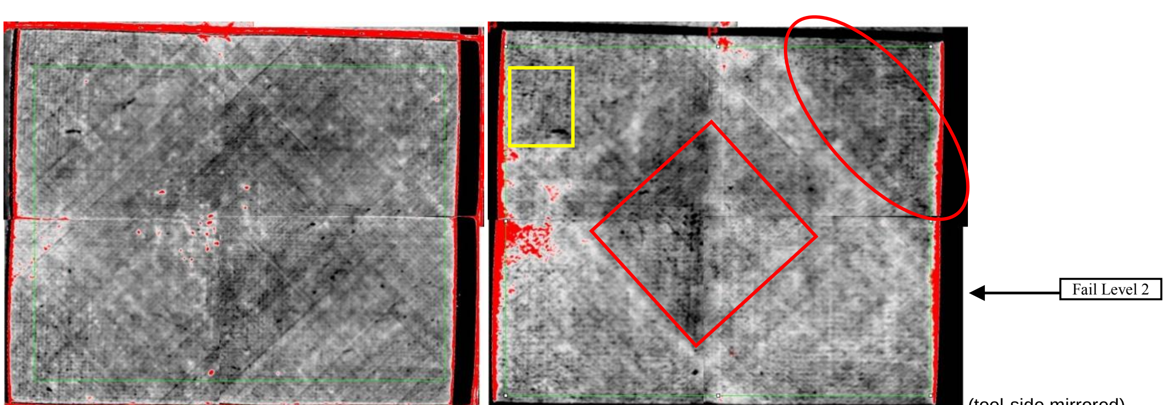


Figure 266. Thermography AS192 (1st Deriv. - 0.42 & 0.94 sec)

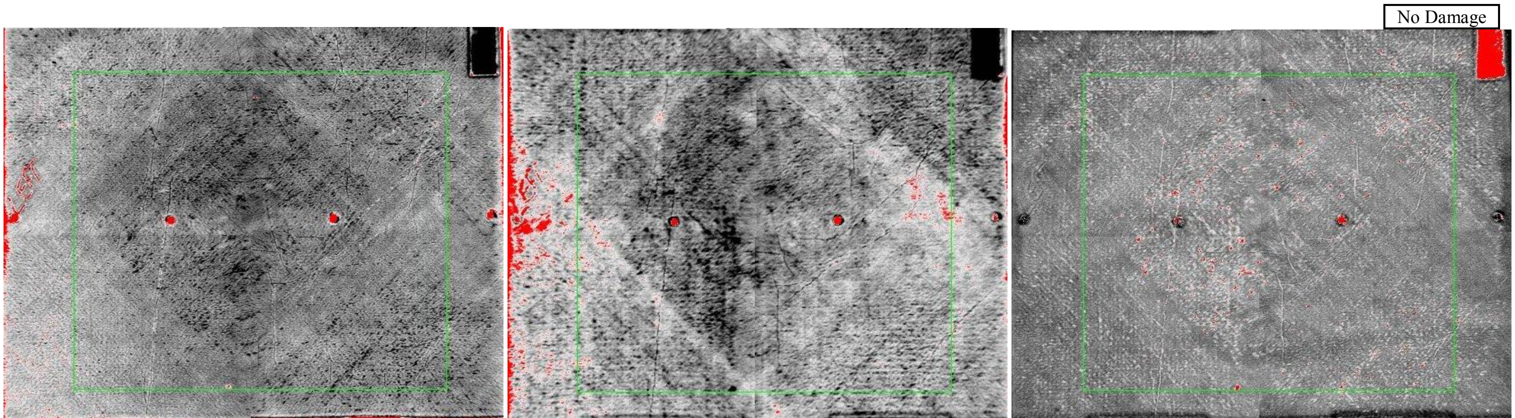


Figure 267. Post-Impact Thermography Panel 192 {IM-28} (1st Deriv. - 0.42s, 0.94s & Peak Ampl.- Pos. 2nd Deriv.)

Optical photomicrographs were taken from 3 sections (in Panels #23 & #159) correlated to areas of high UT attenuation. Many outside studies have found a linear relation between attenuation, porosity and mechanical strength - if porosity voids are spherically shaped and uniformly distributed (e.g. in fabric). However, with UNI laminates the porosity size, shape (often cigar shaped) and distribution dramatically affects void content correlation to UT attenuation - and porosity content to mechanical strengths as well.

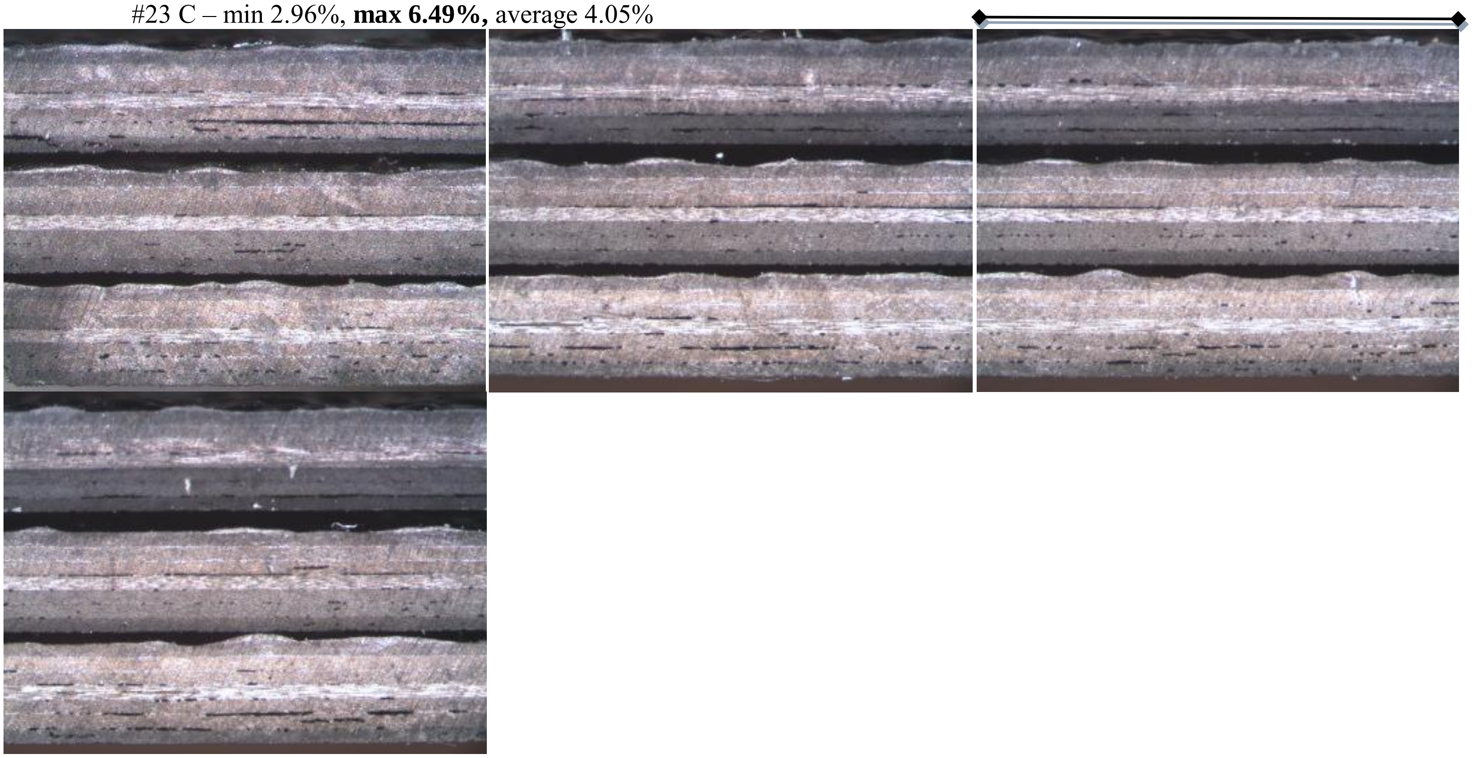
Table 2. PE 5 MHz UT Attenuation vs. Void Content (Optical)

Panel ID #	Porosity averaged over ~1 sq.in. (% VC)	Local PE-UT Attenuation (dB)	Average Max Attenuation in Entire Panel (dB)
159A	3.7	-20	-9
159B	2.9	-18	-9
23	3.9	-19	-10

Photomicrography Analysis for Void Content (Polishes taken in orthogonal directions):

0° →
#159 A – min 3.5%, **max 7.28%,** average 5.4%
#159 B – min 1.4%, max 3.97%, average 2.4 %
#23 C – min 2.96%, **max 6.49%,** average 4.05%

Scale: 0.18”



90° →
#159 A – min 2.58%, max 3.7%, average 3.2%
#159 B – min 1.3%, max 2.9%, average 2.1%
#23 C – min 2.23%, max 4.1%, average 3.62%

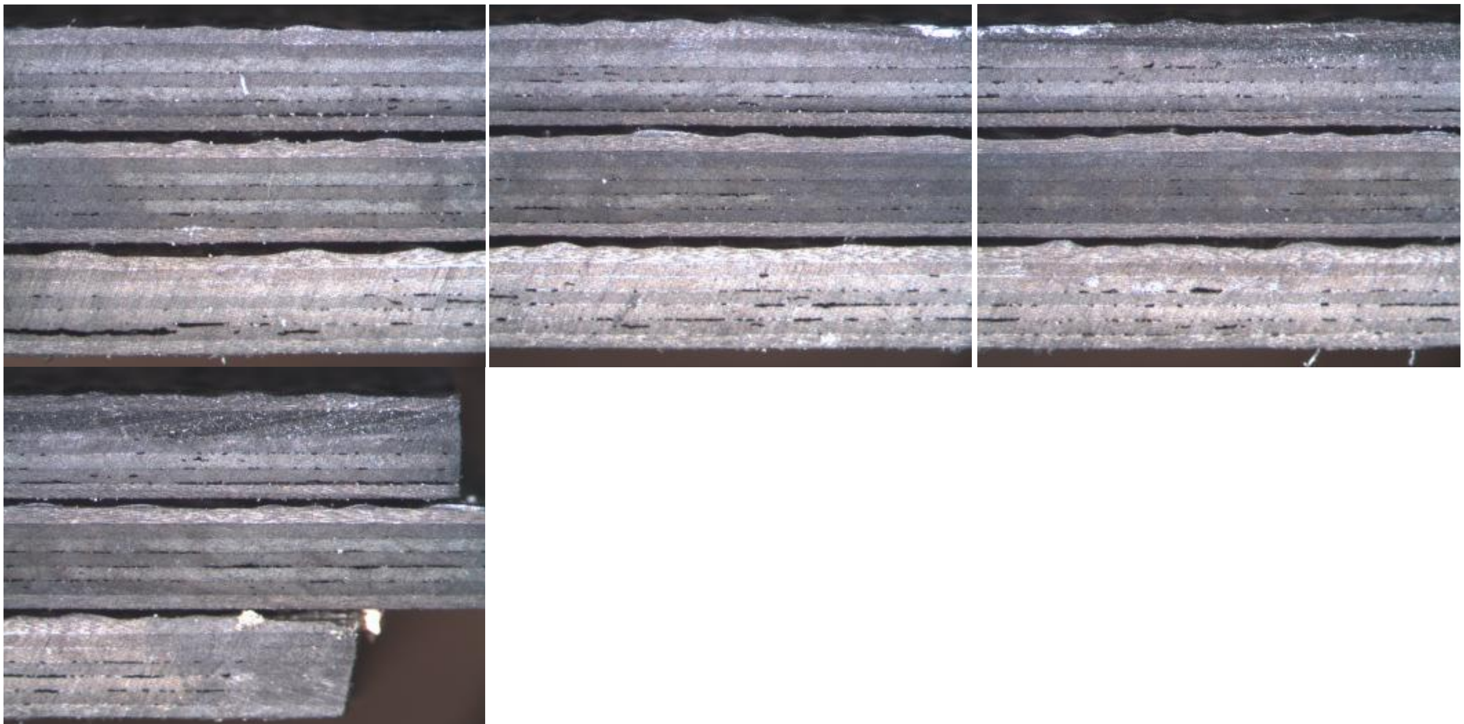
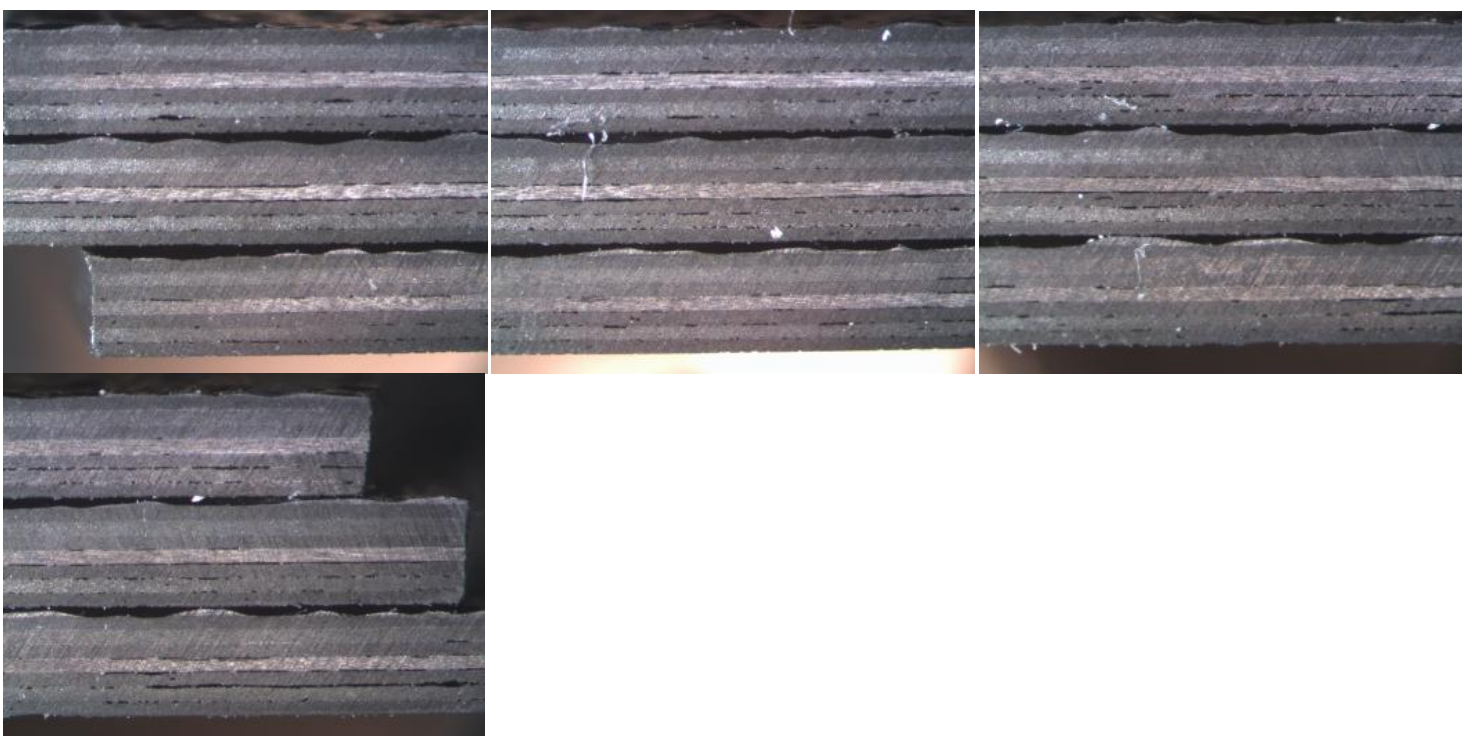
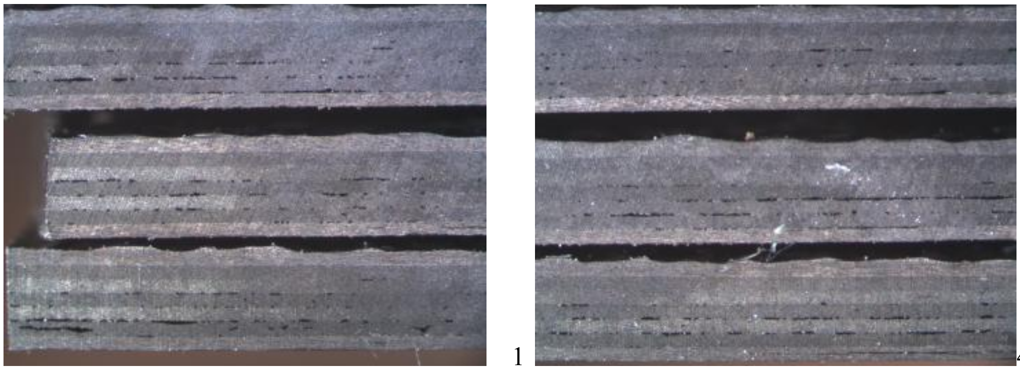


Figure 268. Photomicrographs of sections from Panel 159 (A & B) and Panel 23 (C) {1st polish}

0° →
#159 A – min 1.1%, max 4.0%, average 2.8%
#159 B – min 2.45%, **max 6.4%,** average 4.13%
#23 C – min 2.6%, max 3.45%, average 2.94%



90° →
#159 A – min 2.1%, max 2.76%, average 2.43%
#159 B – min 1.4%, max 3.78%, average 2.59%
#23 C – min 2.89%, **max 8.46%,** average 4.86%



1 4

Figure 269. Photomicrographs of sections from Panel 159 (A & B) and Panel 23 (C) {2nd polish}

0° →
#159 A – min 2.9%, max 4.4%, average 3.7%
#159 B – min 2.5%, max 3.4%, average 2.8%

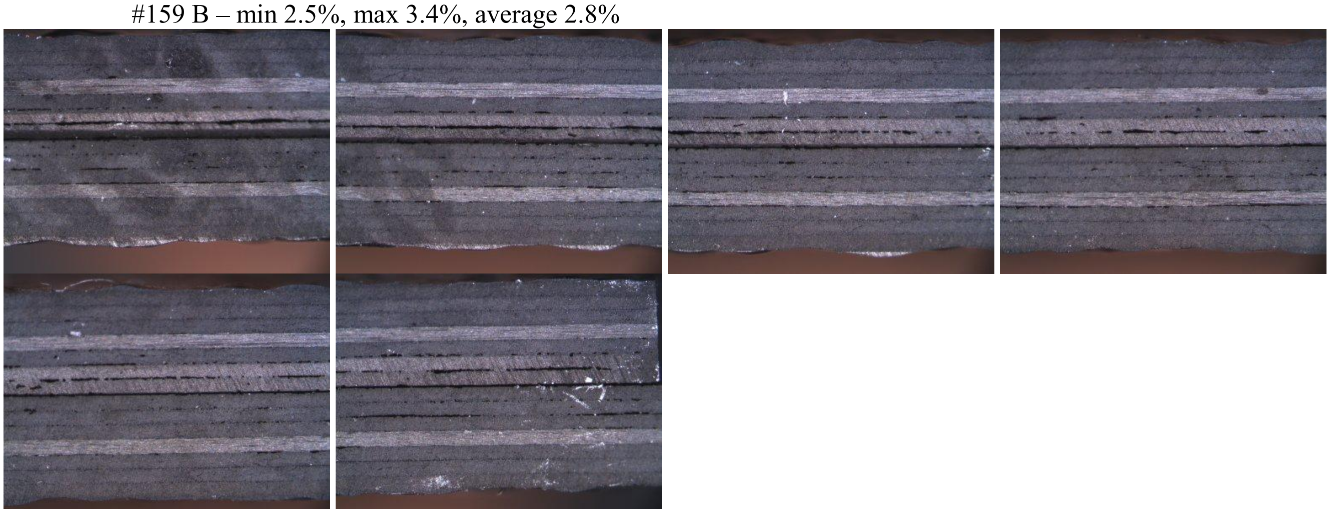


Figure 270. Photomicrographs of sections from Panel 159 (A & B) {3rd polish}

Appendix D -
First-Generation Test Article Impact Testing Pictures

Purpose

This appendix presents the pictures taken of the impact panels before and after impact testing. In some cases where something visually interesting can be seen by looking at the impact test article from an angle, those pictures are presented. Some of the surfaces (especially the carbon epoxy and aluminum) were very shiny, making it difficult to get good images.

Pictures

Figure D-1: Before and after pictures of the front of IM-2.

Figure D-2: Before and after pictures of the back of IM-2.

Figure D-3: Before and after pictures of the front of panel IM-3.

Figure D-4: After picture of the back of panel IM-3.

Figure D-5: Before and after pictures of the front of panel IM-4.

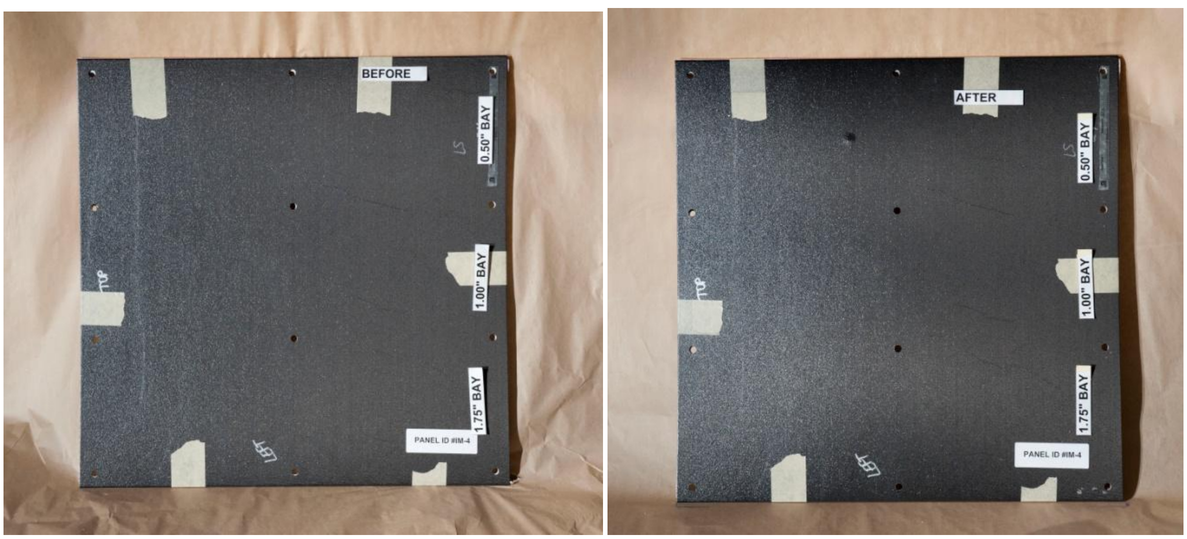


Figure D-6: Before and after pictures of the back of panel IM-4.

Figure D-7: Before and after pictures of the front of panel IM-5.

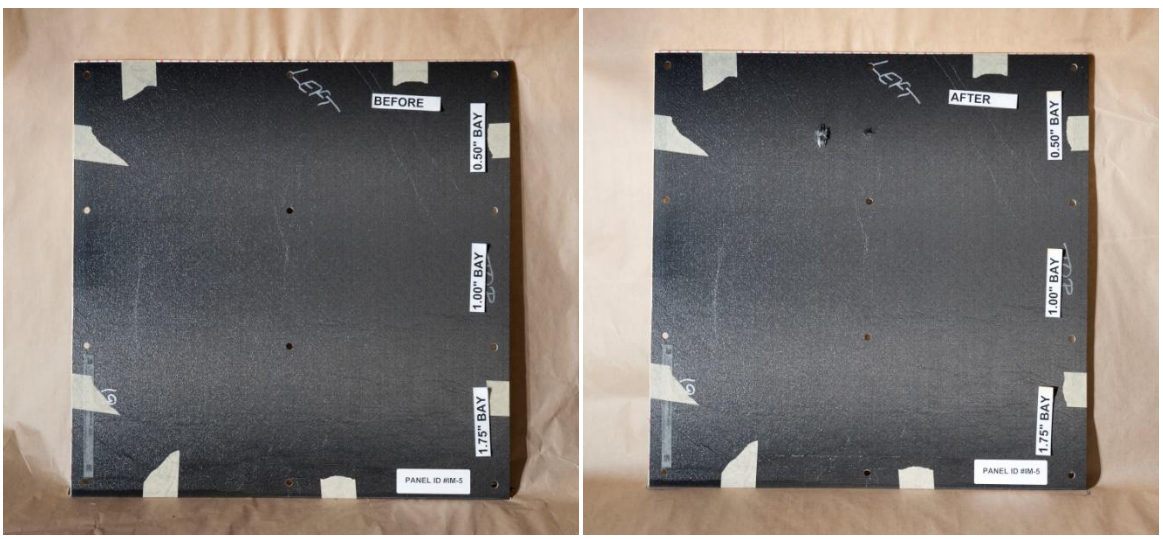


Figure D-8: Before and after pictures of the back of panel IM-5.

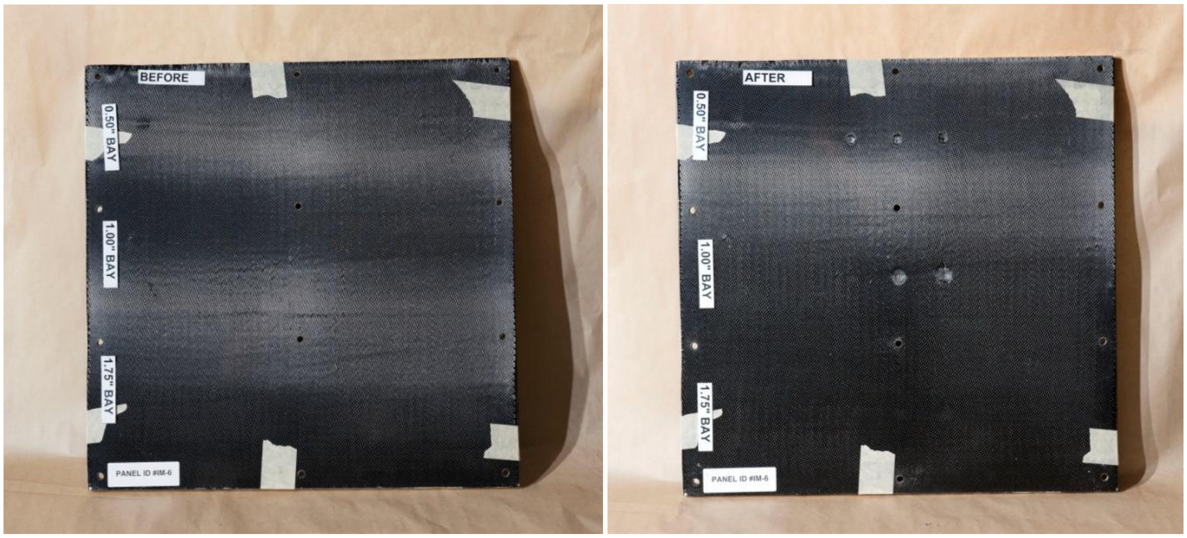


Figure D-9: Before and after pictures of front of panel IM-6.

Figure D-10: Before and after pictures of back of panel IM-6.

Figure D-11: Before and after pictures of front of panel IM-7.

Figure D-12: Before and after pictures of back of panel IM-7.

Figure D-13: Before and after pictures of the front of panel IM-8.

Figure D-14: Before and after pictures of the back of panel IM-8.

Figure D-15: Before and after pictures of the front of panel IM-9.

Figure D-16: Before and after pictures of the back of panel IM-9.

Figure D-17: Before and after pictures of the font of panel IM-10.

Figure D-18: Before and after pictures of the back of panel IM-10.

Figure D-19: Before and after pictures of the front of panel IM-11.

Figure D-20: Before and after pictures of the back of panel IM-11.

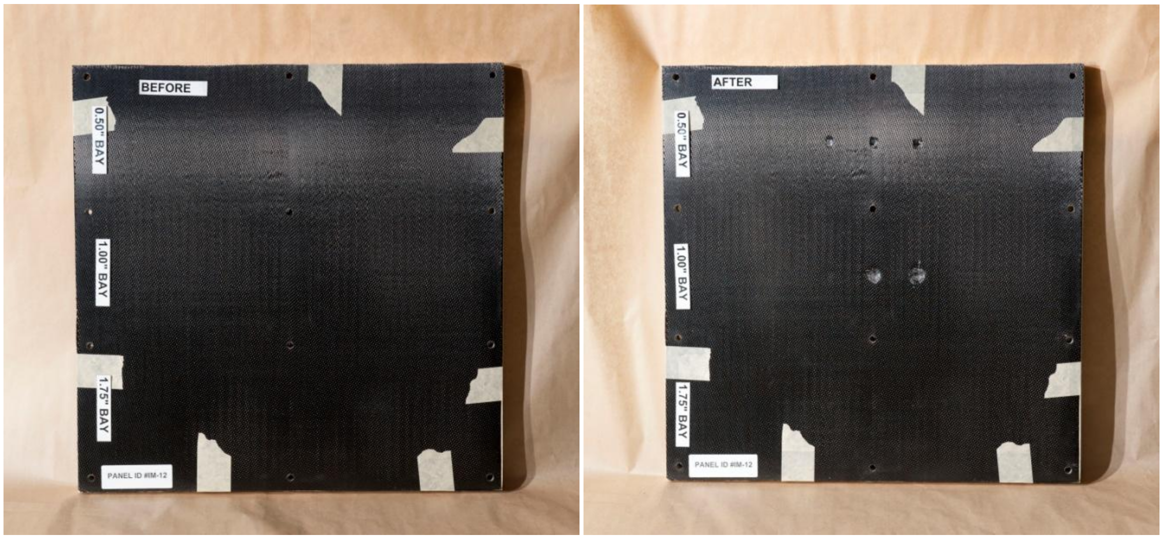


Figure D-21: Before and after pictures of the front of panel IM-12.

Figure D-22: Before and after pictures of the back of panel IM-12.

Figure D-23: Before and after pictures of the front of IM-13.

Figure D-24: Before and after pictures of the back of IM-13.

Figure D-25: Before and after pictures of front of panel IM-14.

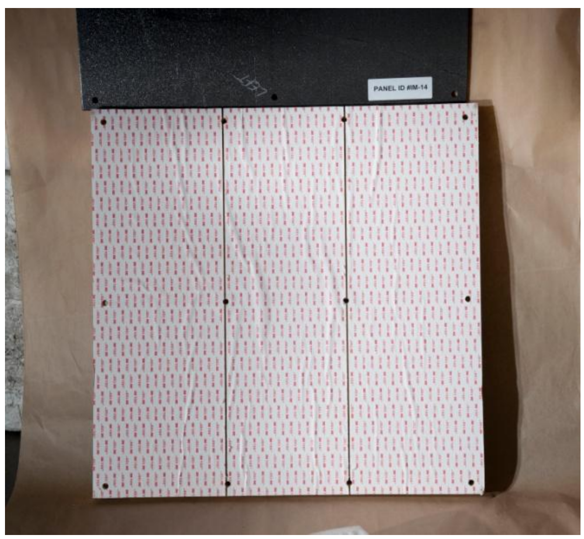


Figure D-26: View of double-sided tape with cut lines on back of panel IM-14.

Figure D-27: Before and after pictures of back of panel IM-14.

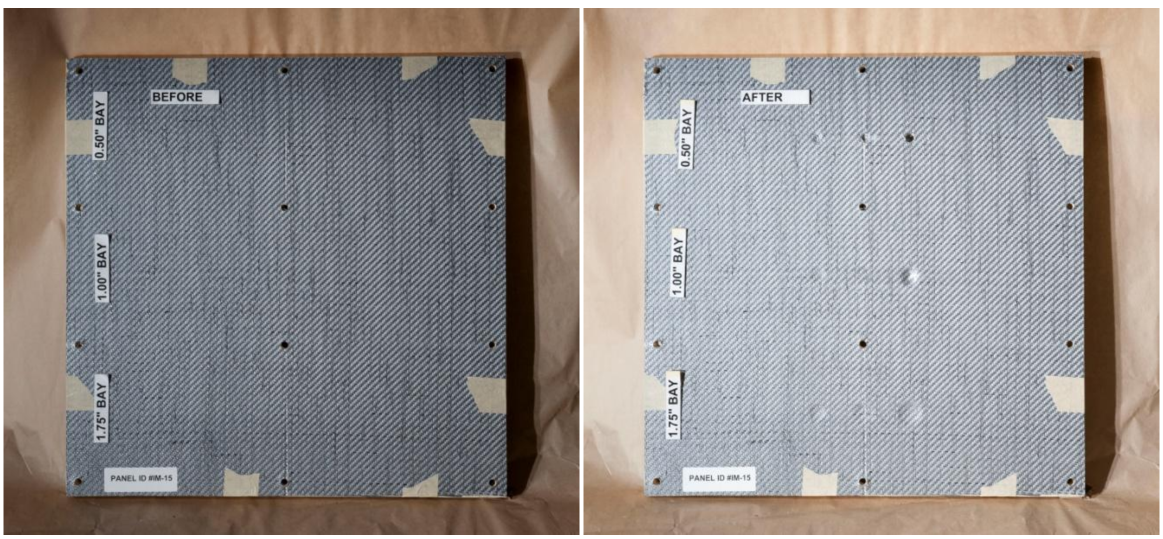


Figure D-28: Before and after pictures of the front of panel IM-15.

Figure D-29: Before and after pictures of the back of panel IM-15.

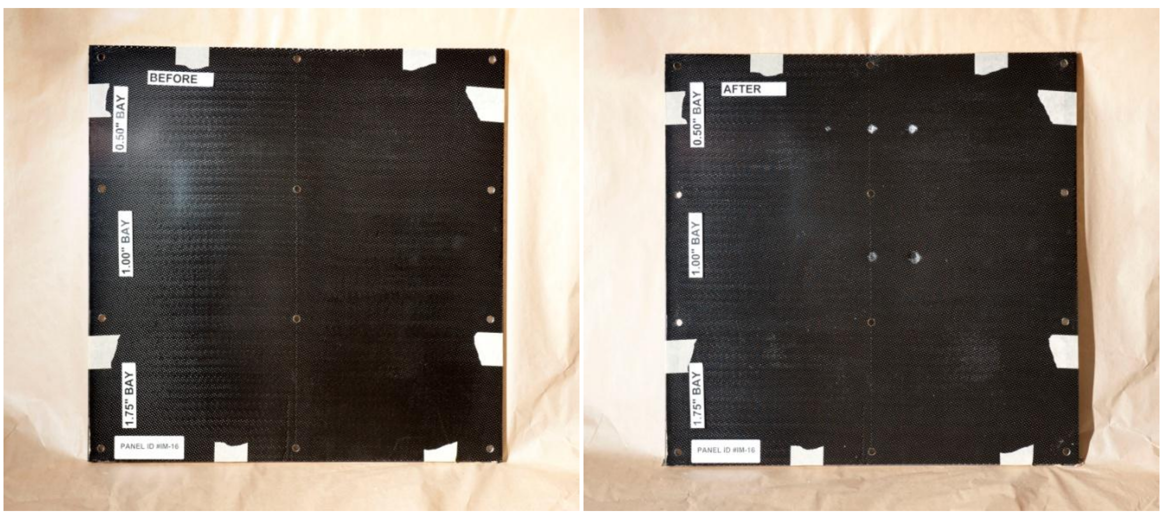


Figure D-30: Before and after pictures of the front of IM-16.

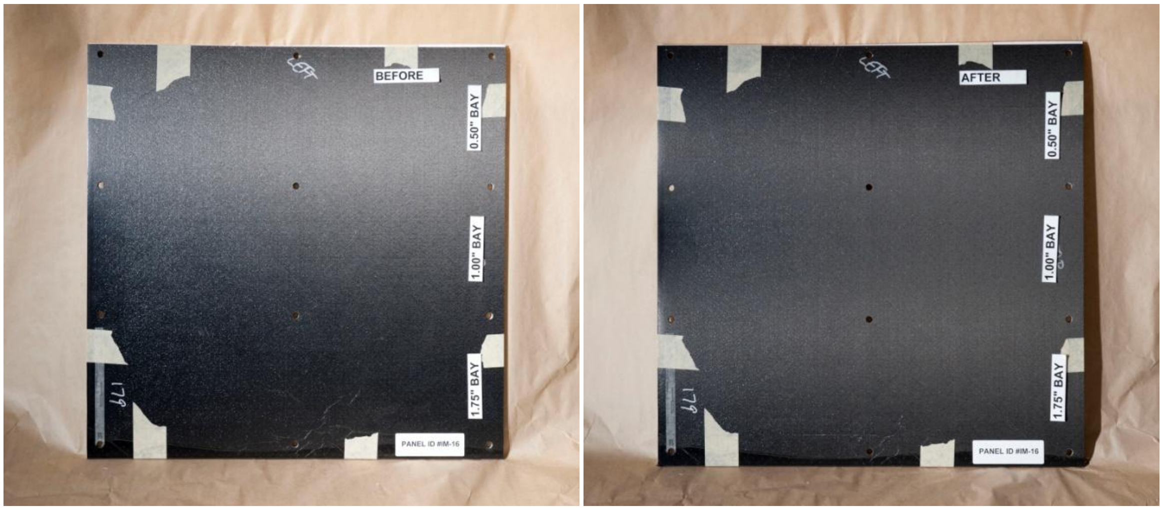


Figure D-31: Before and after pictures of the back of IM-16.

Figure D-32: Before and after pictures of the front of panel IM-17.

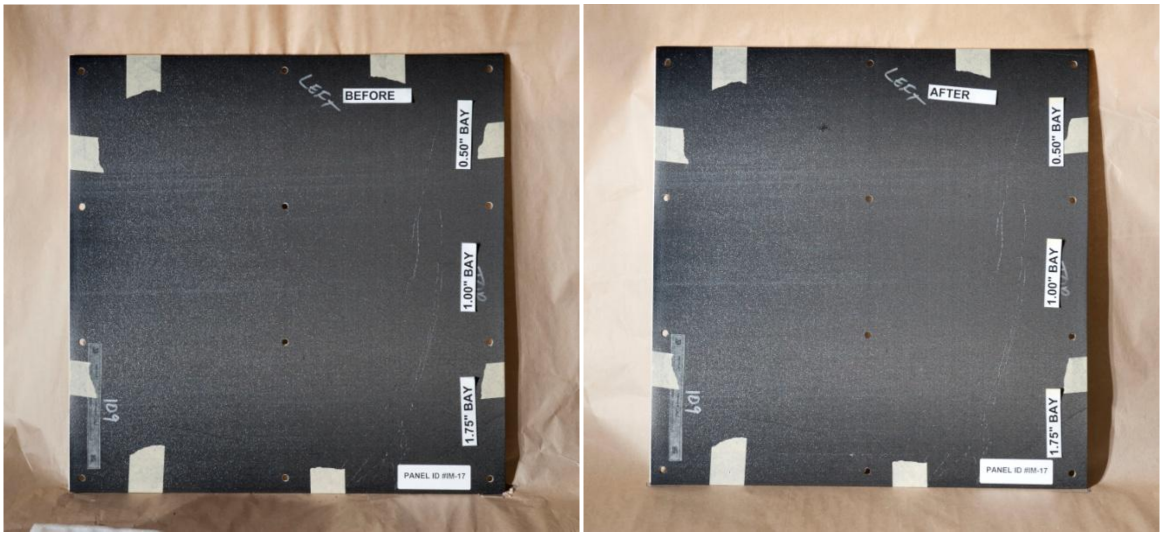


Figure D-33: Before and after pictures of the back of panel IM-17.

Figure D-34: Before and after pictures of the front of panel IM-18.

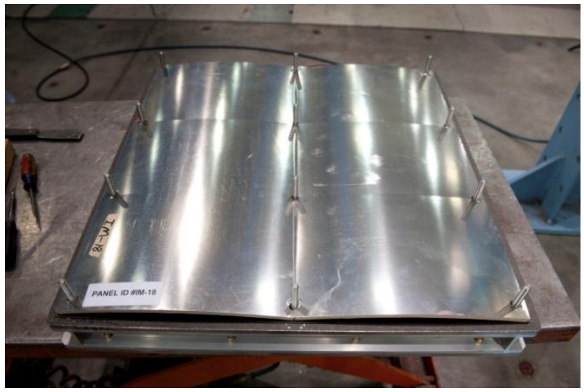


Figure D-35: Before picture of panel IM-18 mounted on test fixture.

Figure D-36: Before and after pictures of the back of panel IM-18.

Figure D-37: Before and after pictures of the front of panel IM-19.

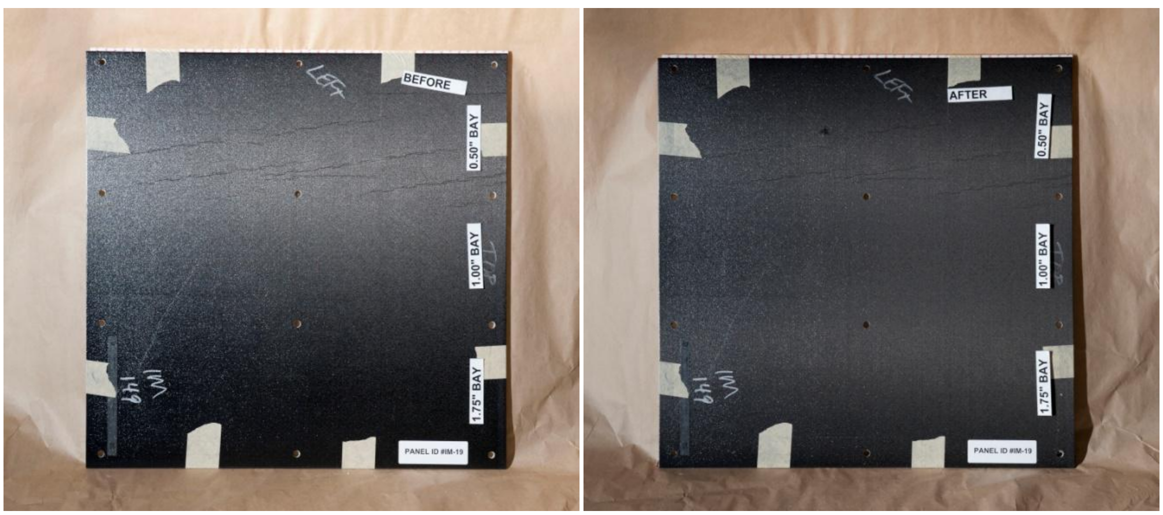


Figure D-38: Before and after pictures of the back of panel IM-19.

Figure D-39: Before and after pictures of the front of panel IM-20.

Figure D-40: Before and after pictures of the back of panel IM-20.

Figure D-41: Before and after pictures of the front of panel IM-21.

Figure D-42: Before and after pictures of the back of panel IM-21.

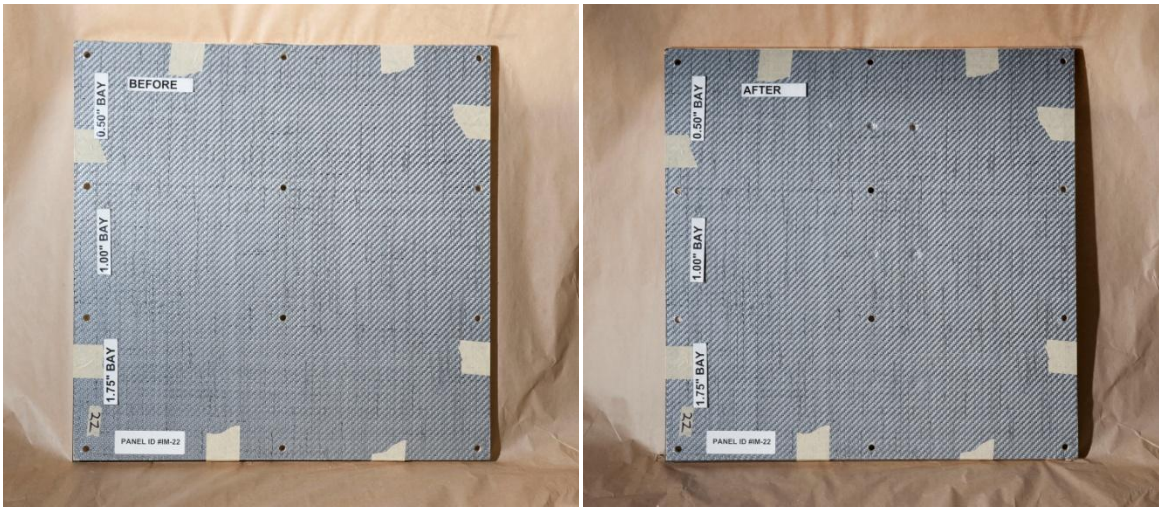


Figure D-43: Before and after pictures of the front of panel IM-22.

Figure D-44: Before and after pictures of the back of panel IM-22.

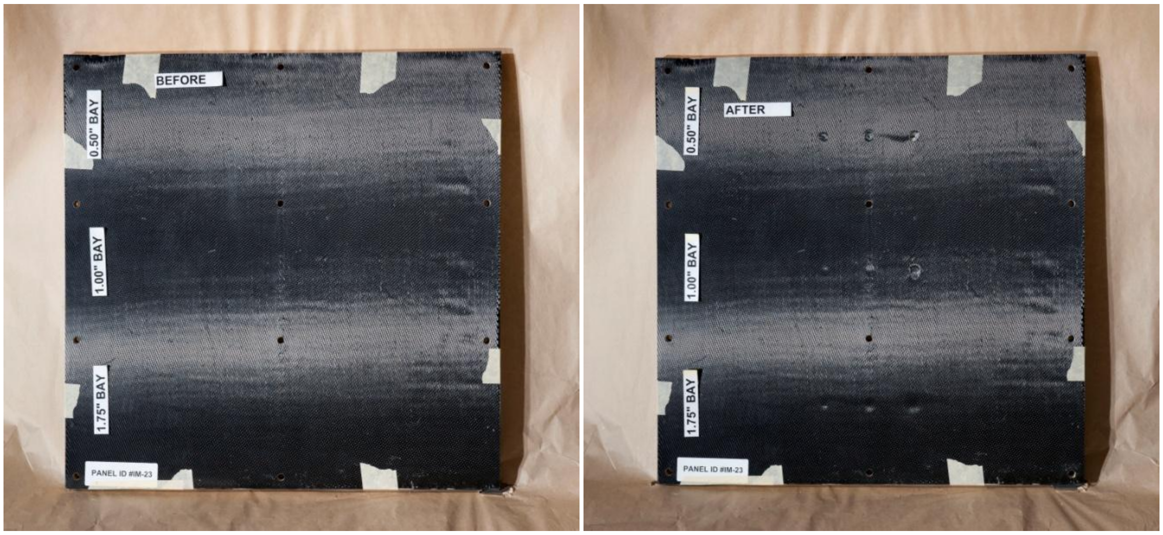


Figure D-45: Before and after pictures of the front of panel IM-23.

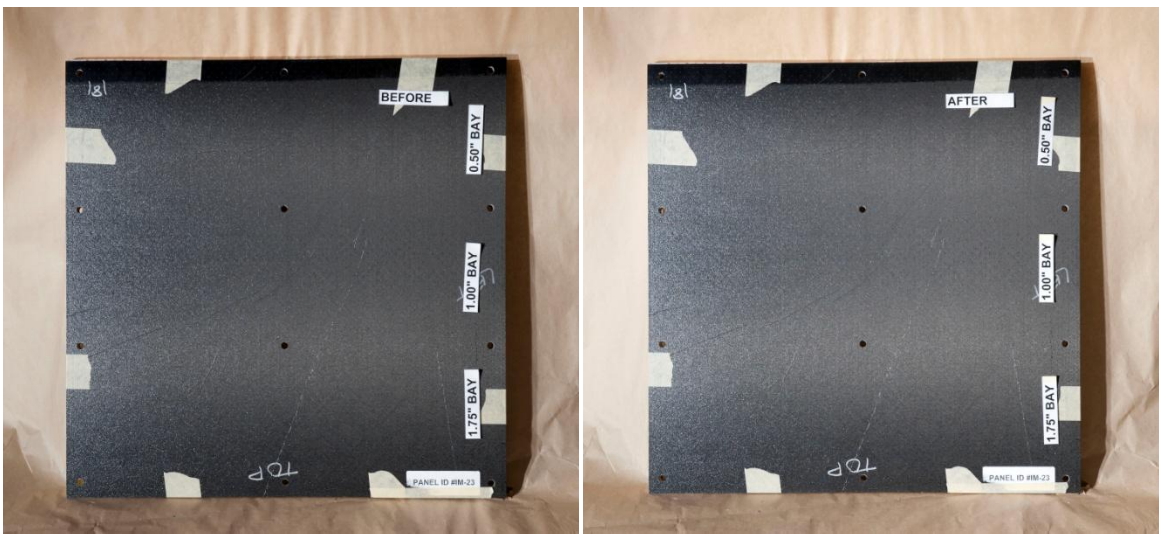


Figure D-46: Before and after pictures of the back of panel IM-23.

Figure D-47: Before and after pictures of the front of panel IM-24.

Figure D-48: Before and after pictures of the back of panel IM-24.

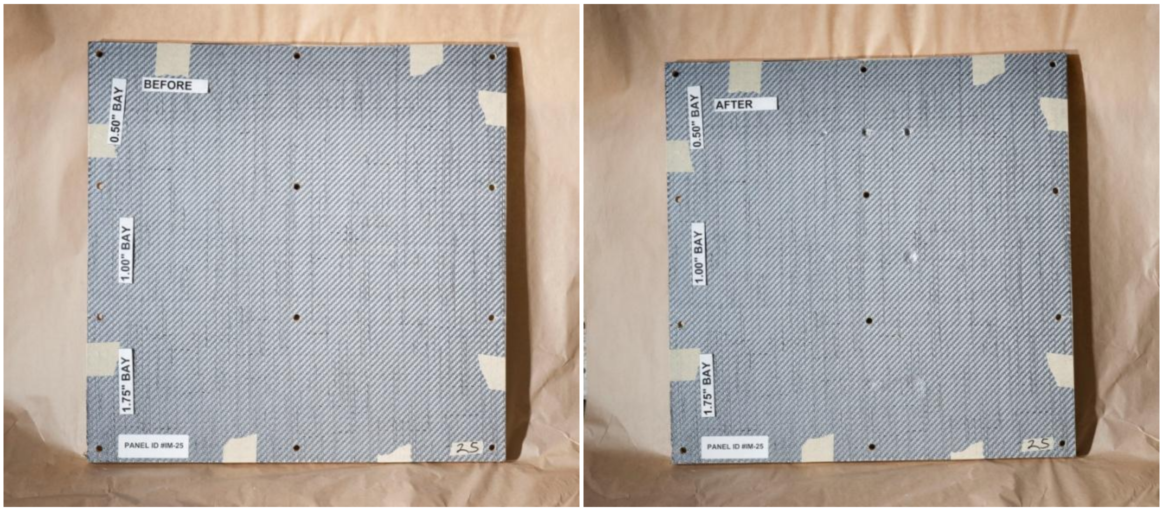


Figure D-49: Before and after pictures of the front of panel IM-25.

Figure D-50: Before and after pictures of the back of panel IM-25.

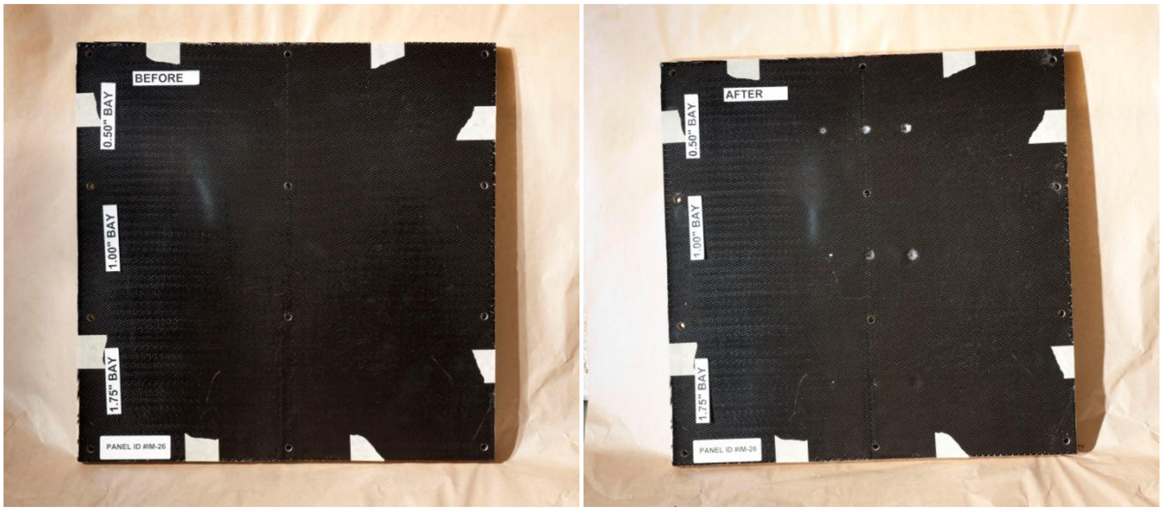


Figure D-51: Before and after pictures of the front of panel IM-26.

Figure D-52: Before and after pictures of the back of panel IM-26.

Figure D-53: Before and after pictures of the front of panel IM-27.

Figure D-54: Before and after pictures of the back of panel IM-27.

Figure D-55: Before and after pictures of the front of panel IM-28.

Figure D-56: Before and after pictures of the back of panel IM-28.

Figure D-57: Cuts in double-sided tape to flatten panel IM-28.

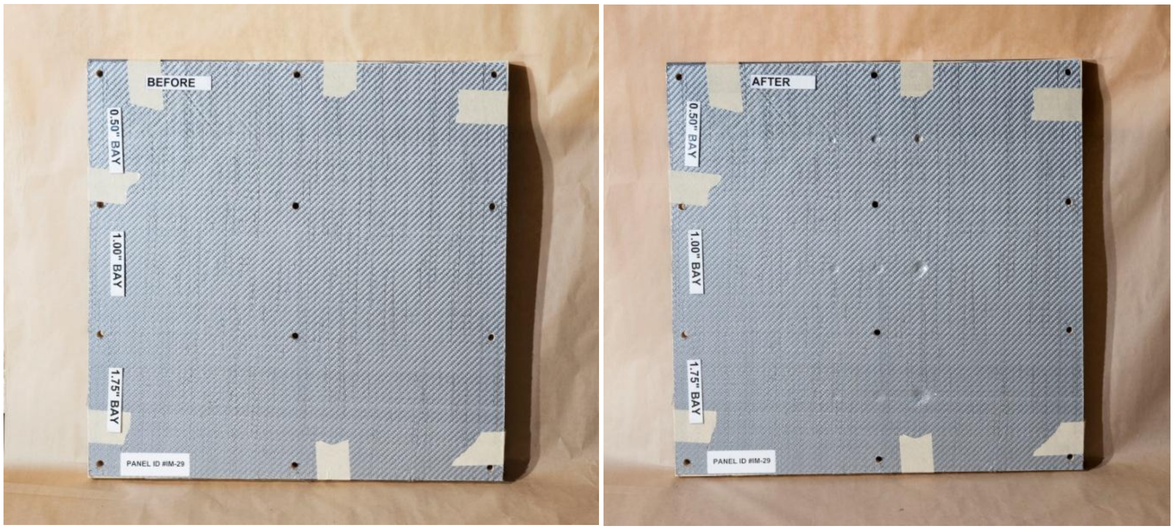


Figure D-58: Before and after pictures of the front of panel IM-29.

Figure D-59: Before and after pictures of the back of panel IM-29.

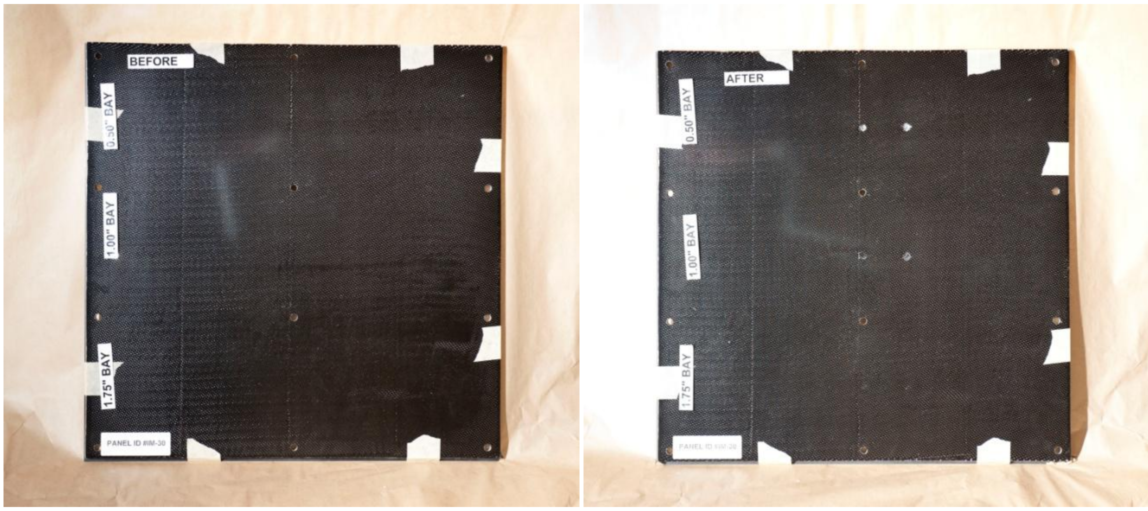


Figure D-60: Before and after pictures of the front of panel IM-30.

Figure D-61: Before and after pictures of the back of panel IM-30.

Figure D-62: Before and after pictures of the front of panel IM-31.

Figure D-63: Before and after pictures of the back of panel IM-31.

Figure D-64: Before and after pictures of the front of panel IM-32.

Figure D-65: After impact picture of back of panel IM-32.

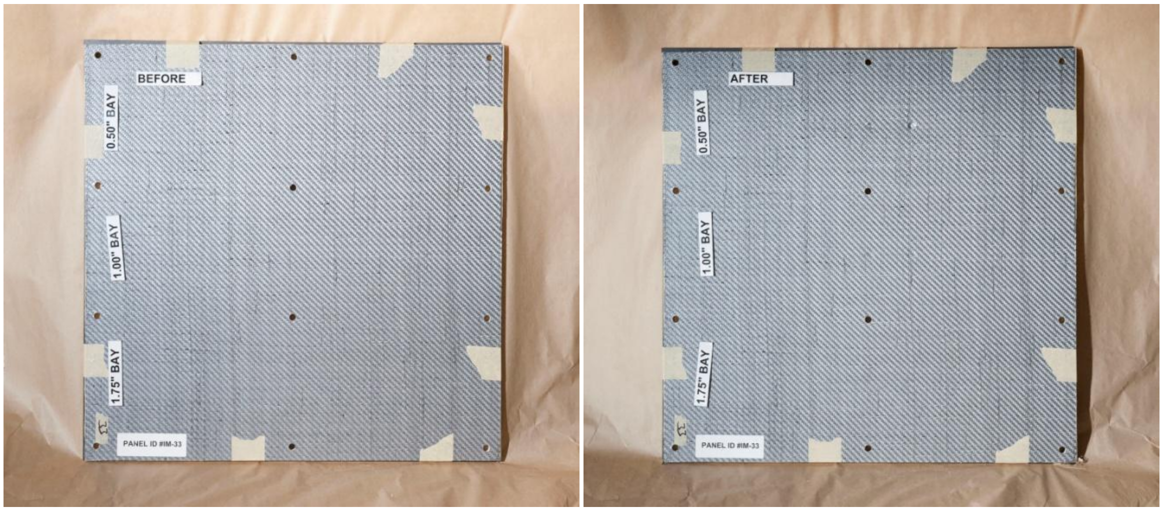


Figure D-66: Before and after pictures of the front of panel IM-33.

Figure D-67: Before and after pictures of the back of panel IM-33.

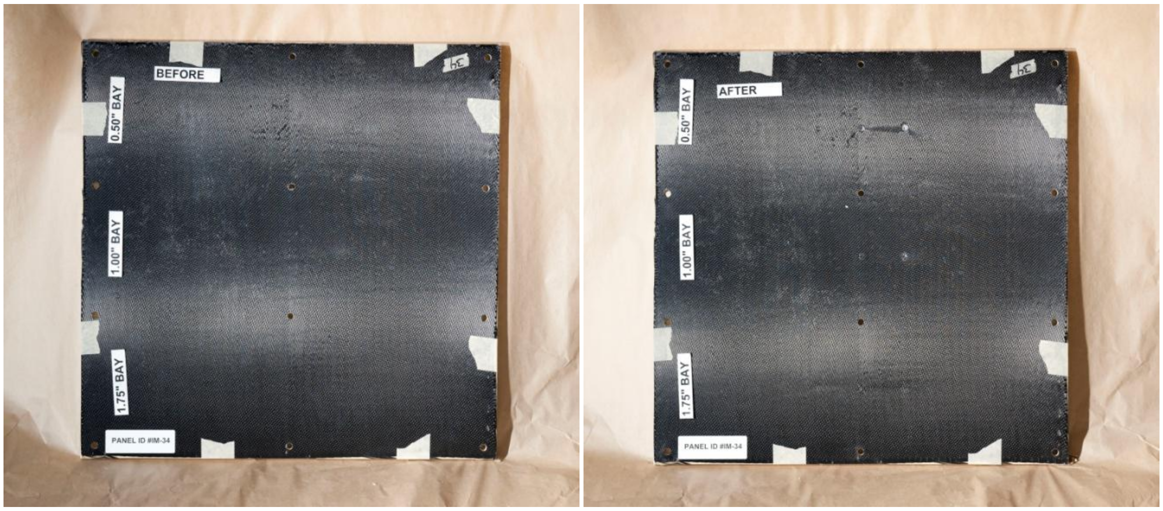


Figure D-68: Before and after pictures of the front of panel IM-34.

Figure D-69: Before and after pictures of the back of panel IM-34.

Figure D-70: Before and after pictures of the front of panel IM-35.

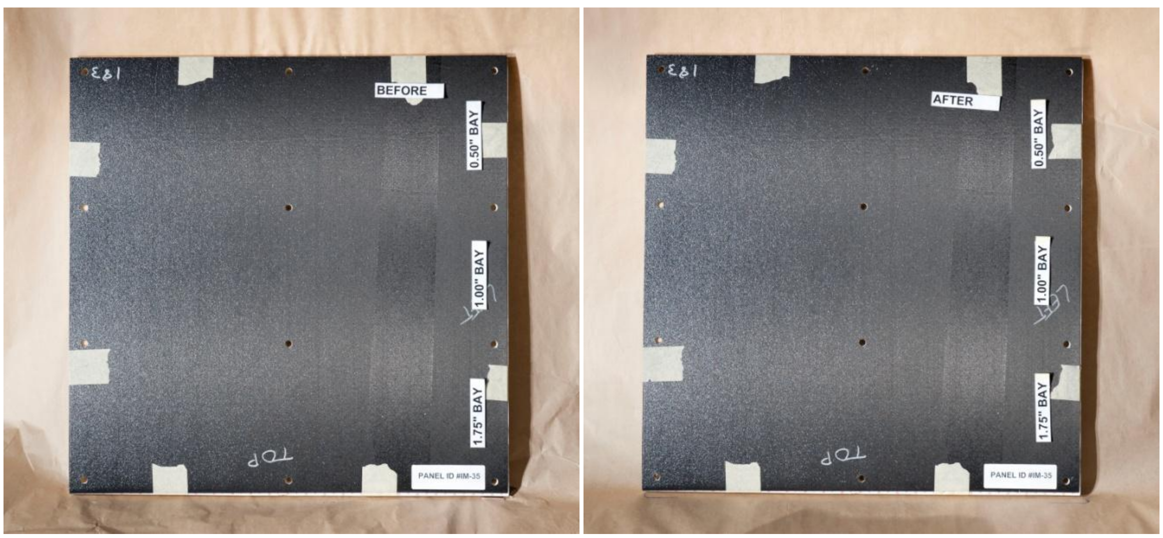


Figure D-71: Before and after pictures of the back of panel IM-35.

Figure D-72: Before and after pictures of the front of panel IM-36.

Figure D-73: Before and after pictures of the back of panel IM-36.

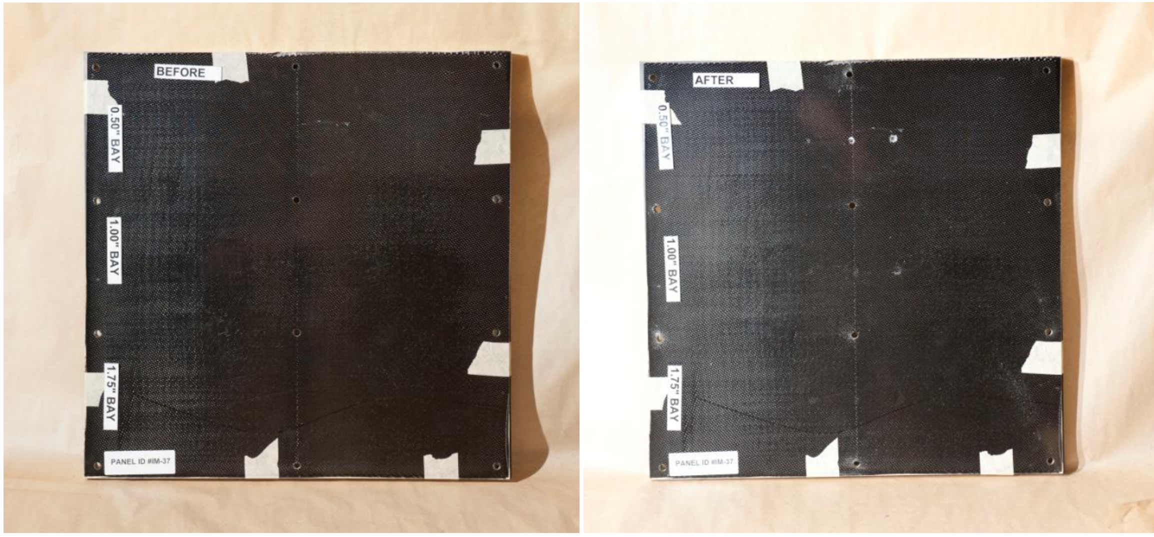


Figure D-74: Before and after pictures of the front of panel IM-37.

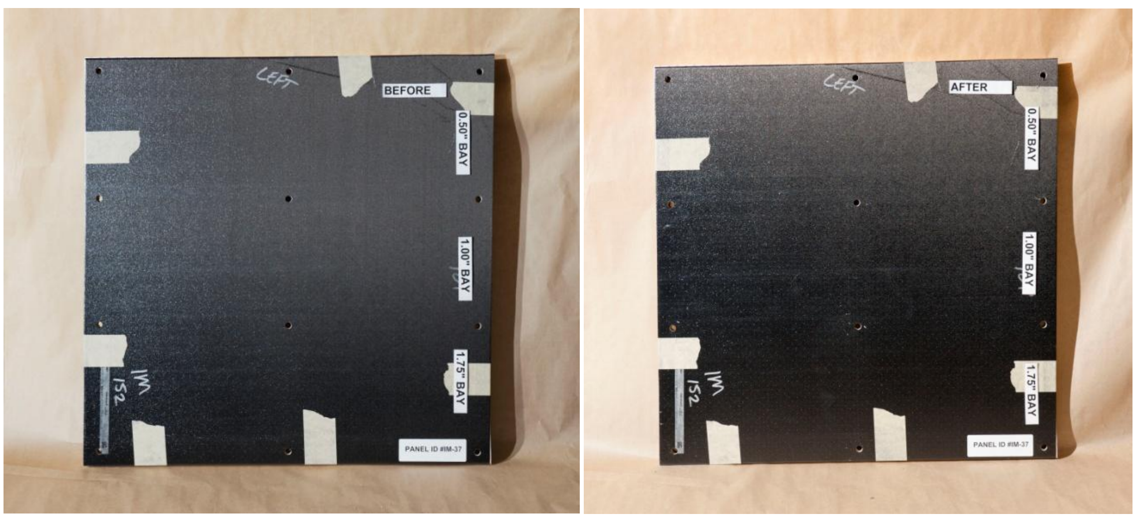


Figure D-75: Before and after pictures of the back of panel IM-37.

Figure D-76: Before and after pictures of the front of panel IM-38.

Figure D-77: Before and after pictures of the back of panel IM-38.

Figure D-78: Before and after pictures of the front of panel IM-39.

Figure D-79: Before and after pictures of the back of panel IM-39.

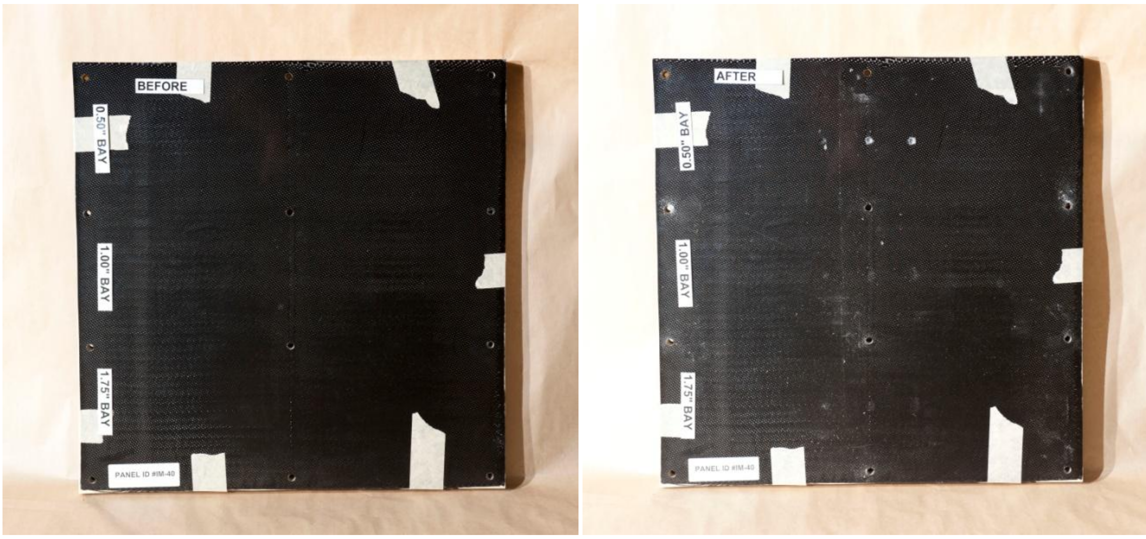


Figure D-80: Before and after pictures of the front of panel IM-40.

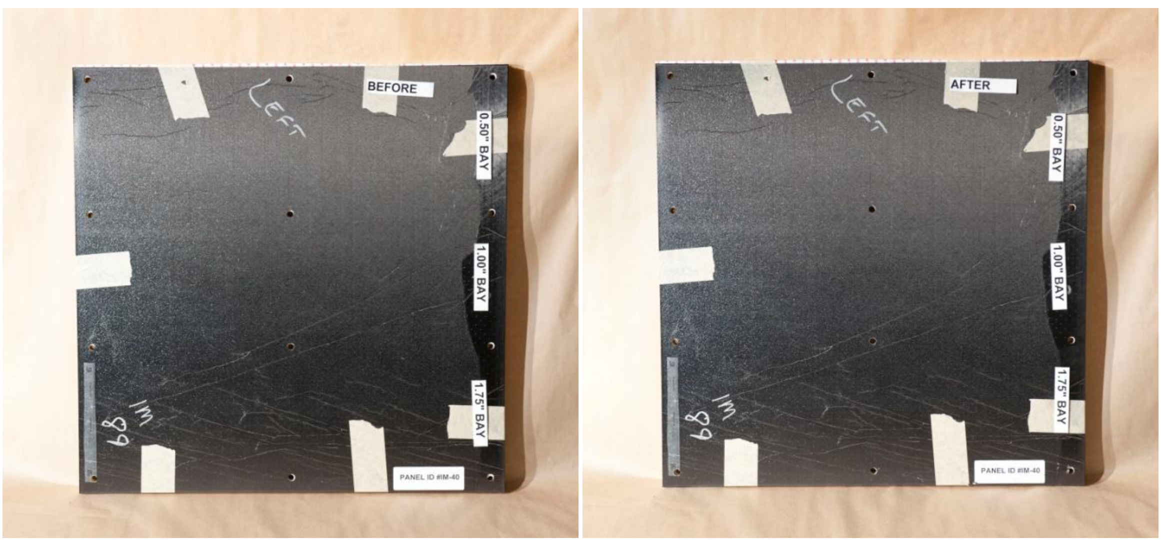


Figure D-81: Before and after pictures of the back of panel IM-40.

Figure D-82: Before and after pictures of the front of panel IM-41.

Figure D-83: Before and after pictures of the back of panel IM-41.

Figure D-84: Before and after pictures of the front of panel IM-43.

Figure D-85: Before and after pictures of the back of panel IM-43.

Figure D-86: Before and after pictures of the front of panel IM-44.

Figure D-87: Before and after pictures of the back of panel IM-44.

Figure D-88: Side view of back of panel IM-44.

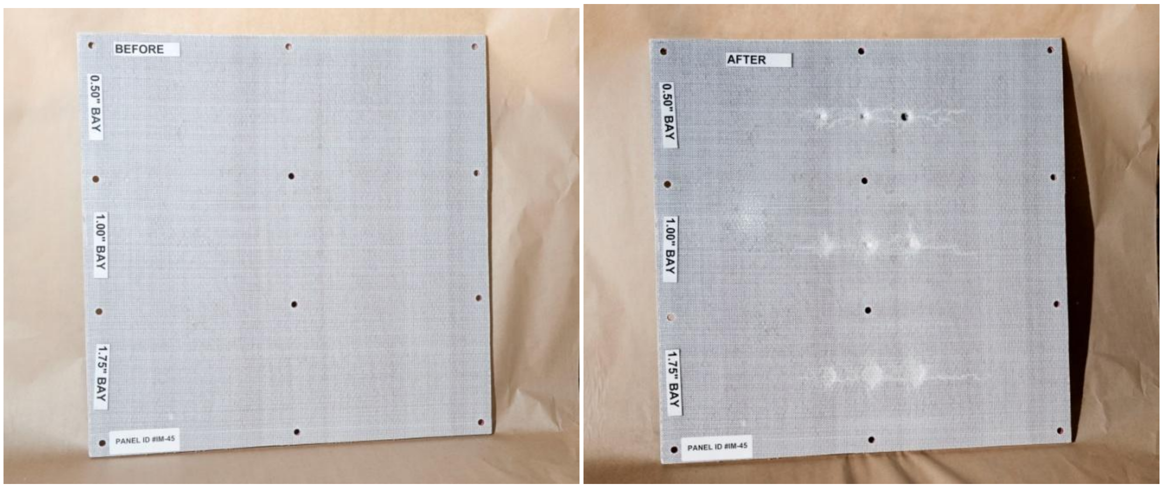


Figure D-89: Before and after pictures of the front of panel IM-45.

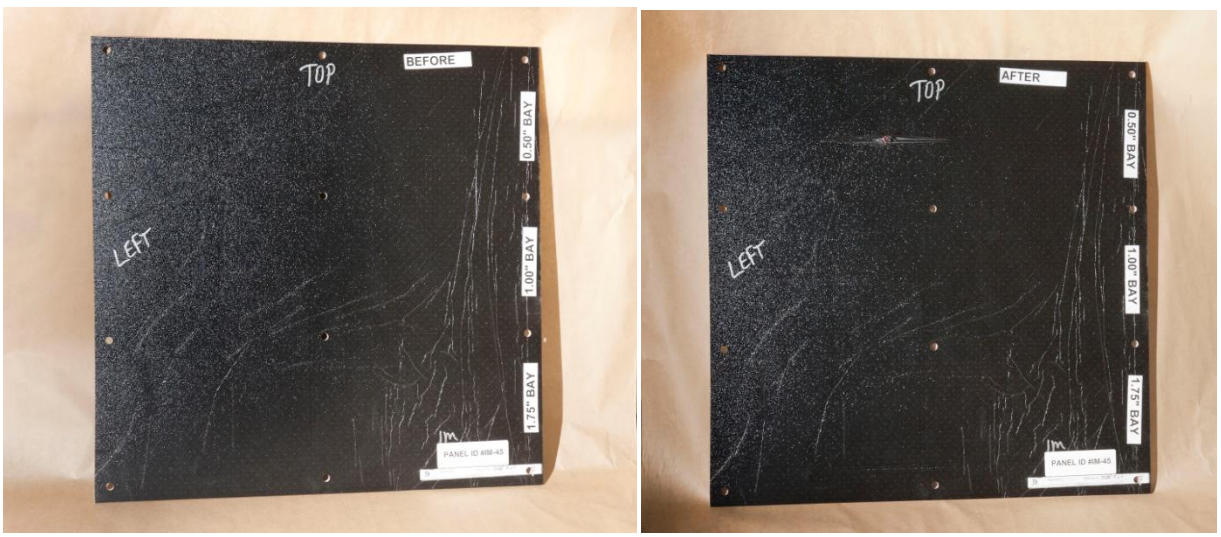


Figure D-90: Before and after pictures of the back of panel IM-45.

Figure D-91: 0.5" impactor at 250 in-lbs penetrating base panel IM-45.

Figure D-92: Before and after pictures of the front of panel IM-46.

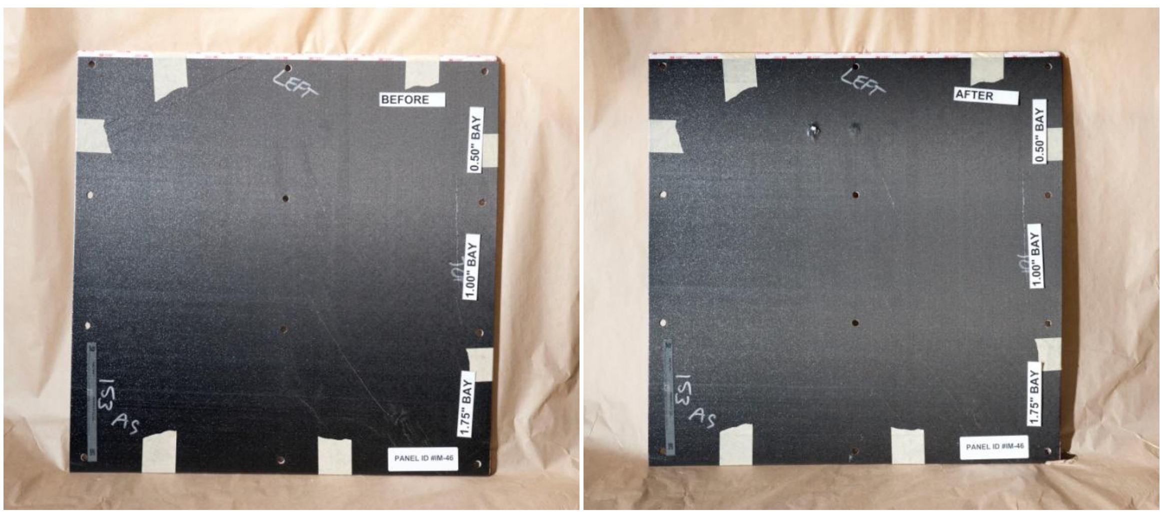


Figure D-93: Before and after pictures of the back of panel IM-46.

Figure D-**94**: Before and after pictures of the front of panel IM-47.

Figure D-95: Before and after pictures of the back of panel IM-47.

Figure D-96: Split from 0.5" impactor at 250 in-lbs in panel IM-47.

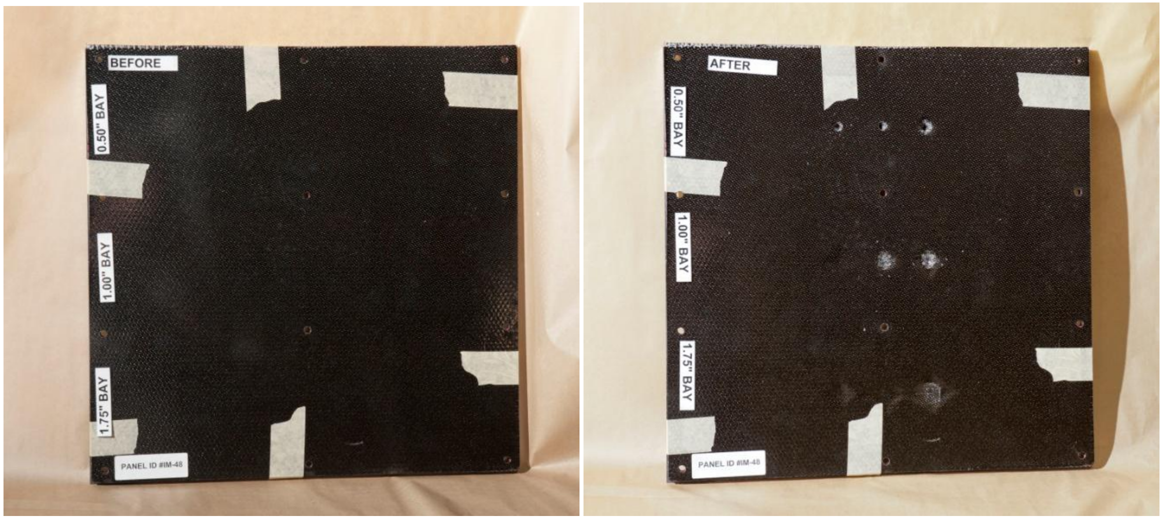


Figure D-97: Before and after pictures of the front of panel IM-48.

Figure D-98: Before and after pictures of the back of panel IM-48.

Figure D-99: Before and after pictures of the front of panel IM-49.

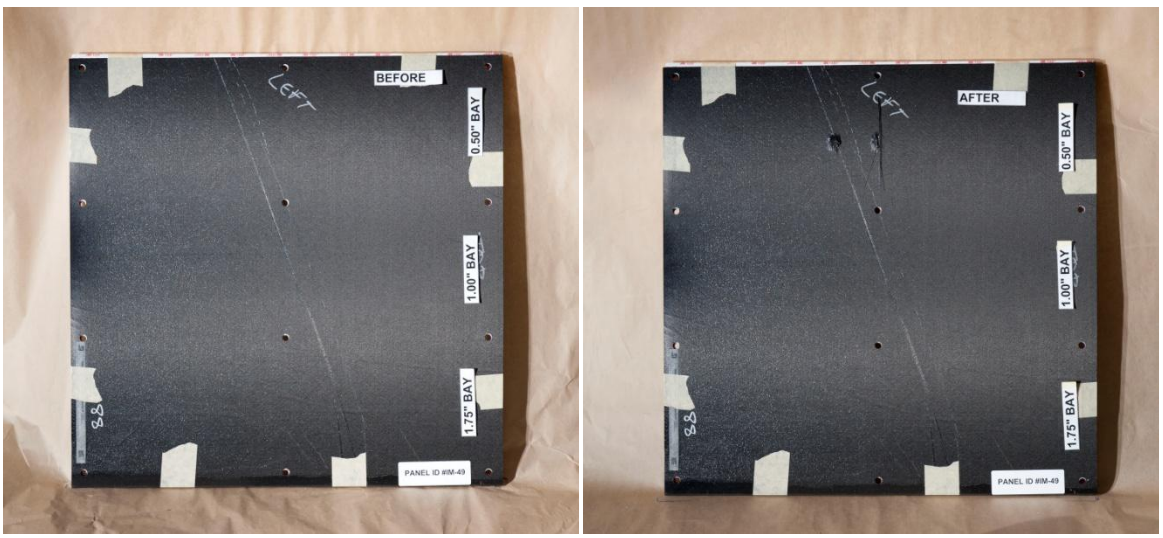


Figure D-100: Before and after pictures of the back of panel IM-49.

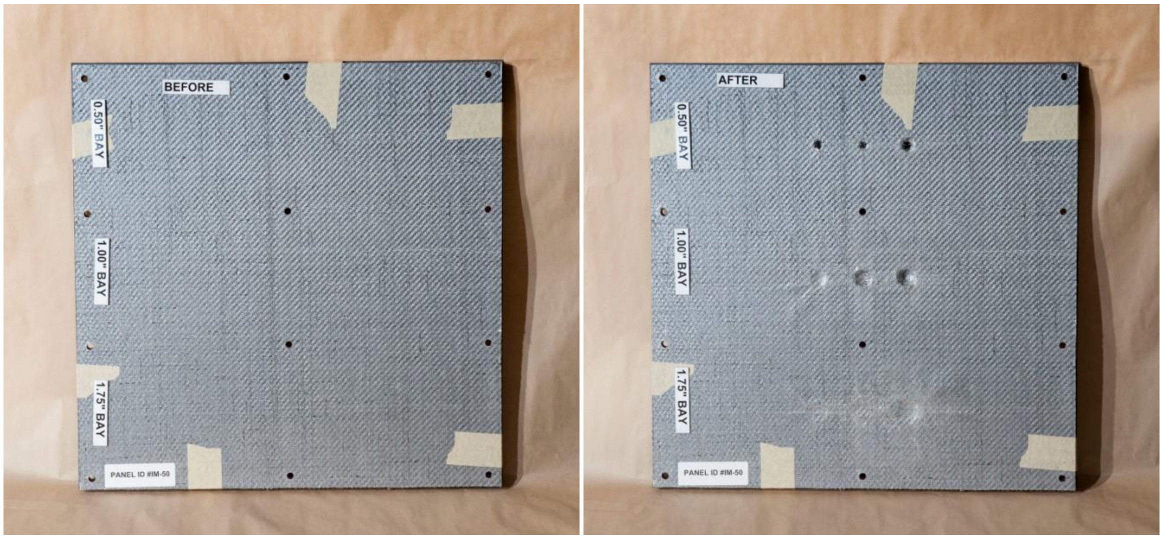


Figure D-101: Before and after pictures of the front of panel IM-50.

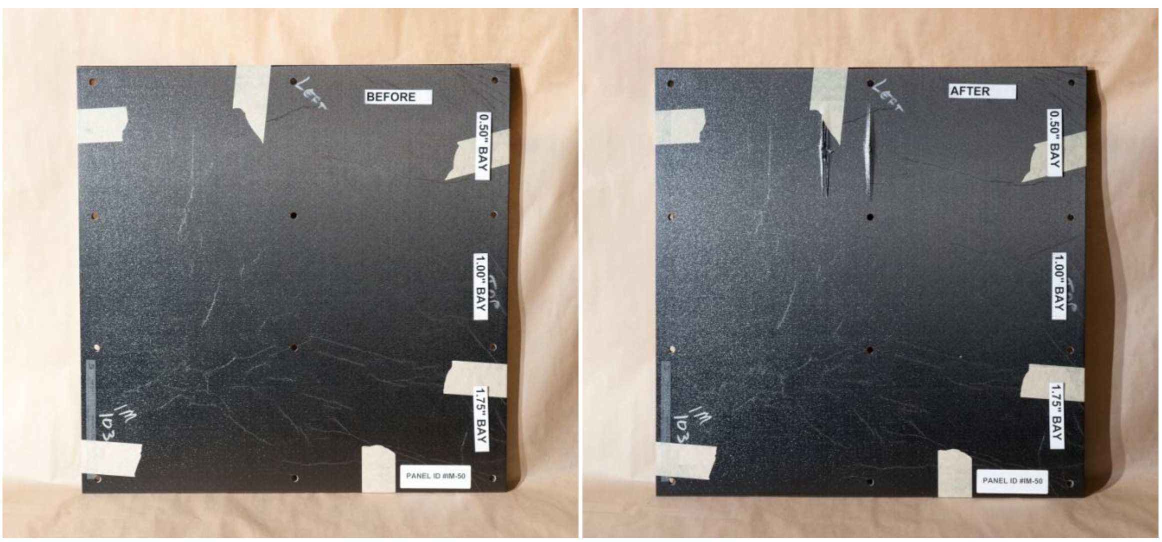


Figure D-102: Before and after pictures of the back of panel IM-50.

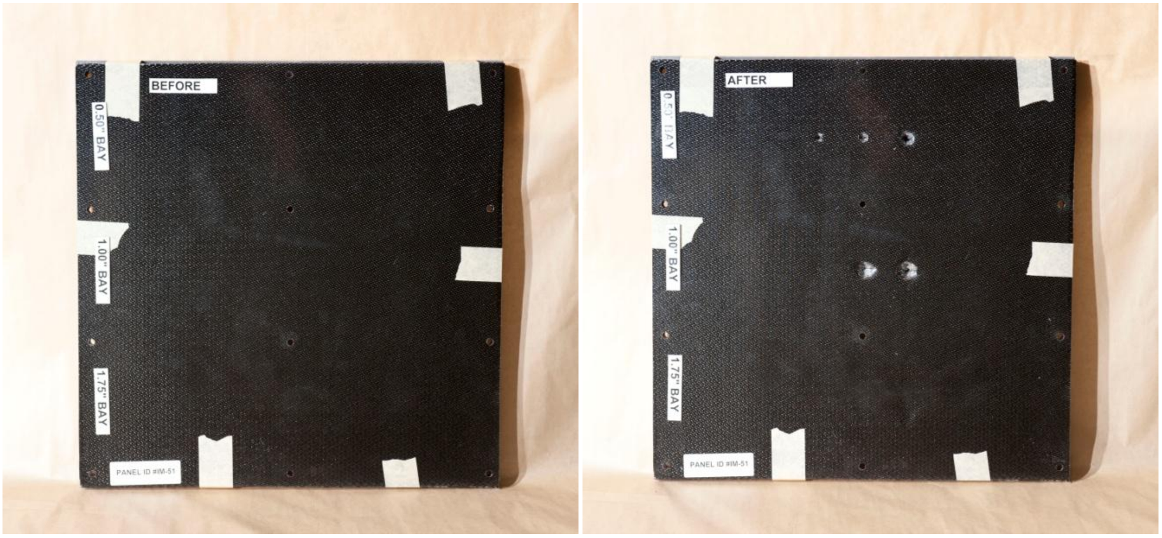


Figure D-103: Before and after pictures of the front of panel IM-51.

Figure D-104: Before and after pictures of the back of panel IM-51.

Figure D-105: Side view of front of panel IM-51 after impact.

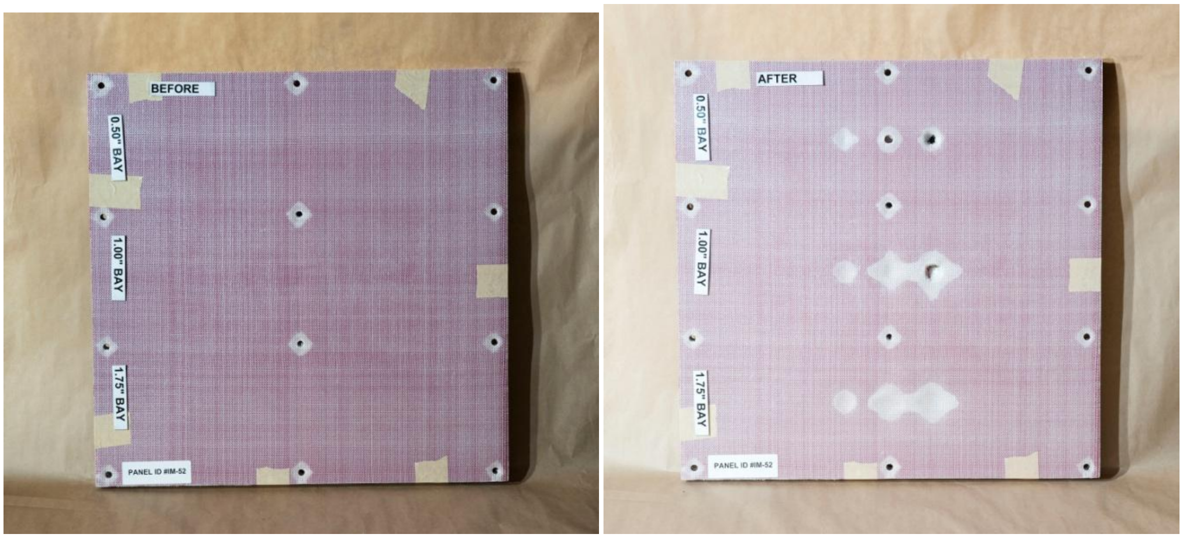


Figure D-106: Before and after pictures of front of panel IM-52.

Figure D-107: Before and after pictures of the back of panel IM-52.

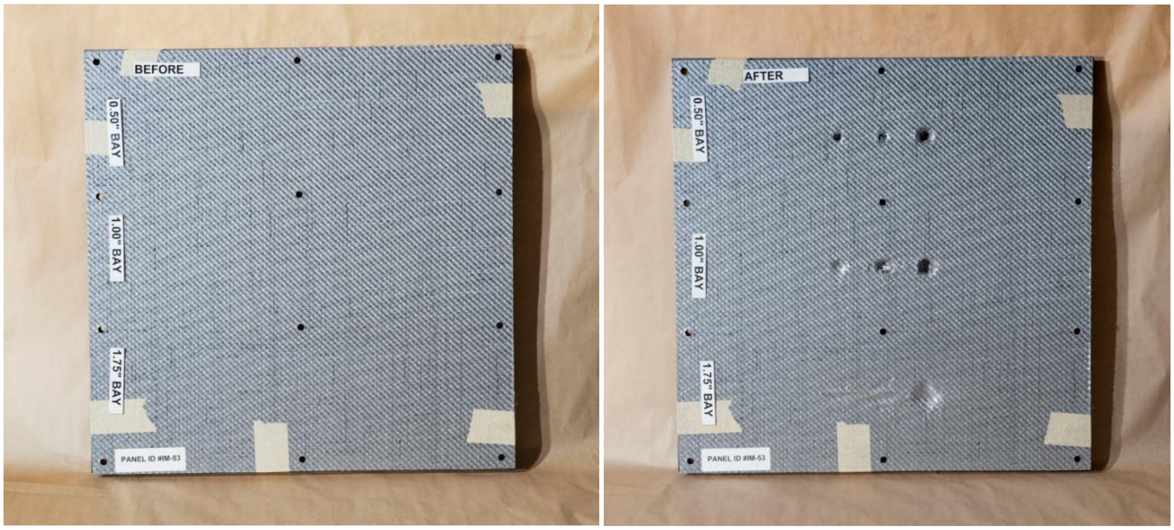


Figure D-108: Before and after pictures of the front of panel IM-53.

Figure D-109: Before and after pictures of the back of panel IM-53.

Figure D-110: Before and after pictures of the front of panel IM-54.

Figure D-111: Before and after pictures of the back of panel IM-54.

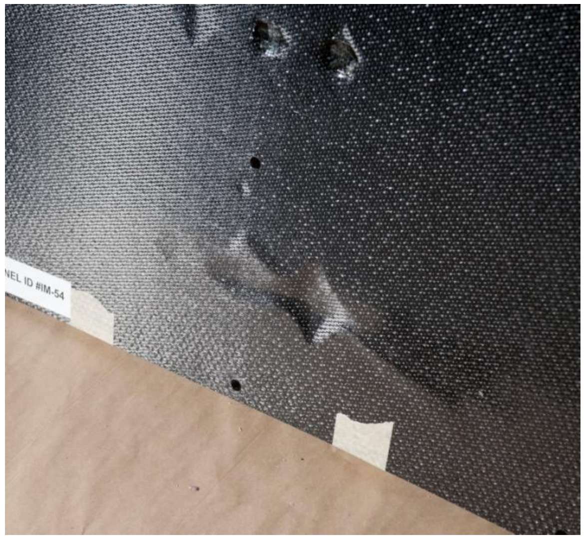


Figure D-112: Up close picture of front of panel IM-54 after impact.

Figure D-113: Before and after pictures of the front of panel IM-55.

Figure D-114: Before and after pictures of the back of panel IM-55.

Figure D-115: Before and after pictures of the front of panel IM-56.

Figure D-116: Before and after pictures of the back of panel IM-56.

Figure D-117: Before and after pictures of the front of panel IM-57.

Figure D-118: Before and after pictures of the back of panel IM-57.

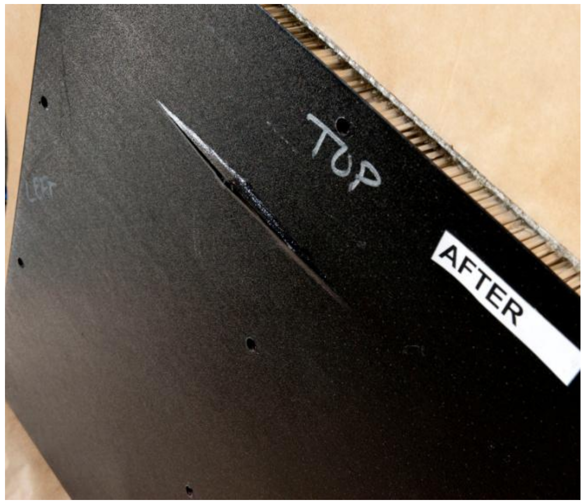


Figure D-119: Side close up of back of panel IM-57.

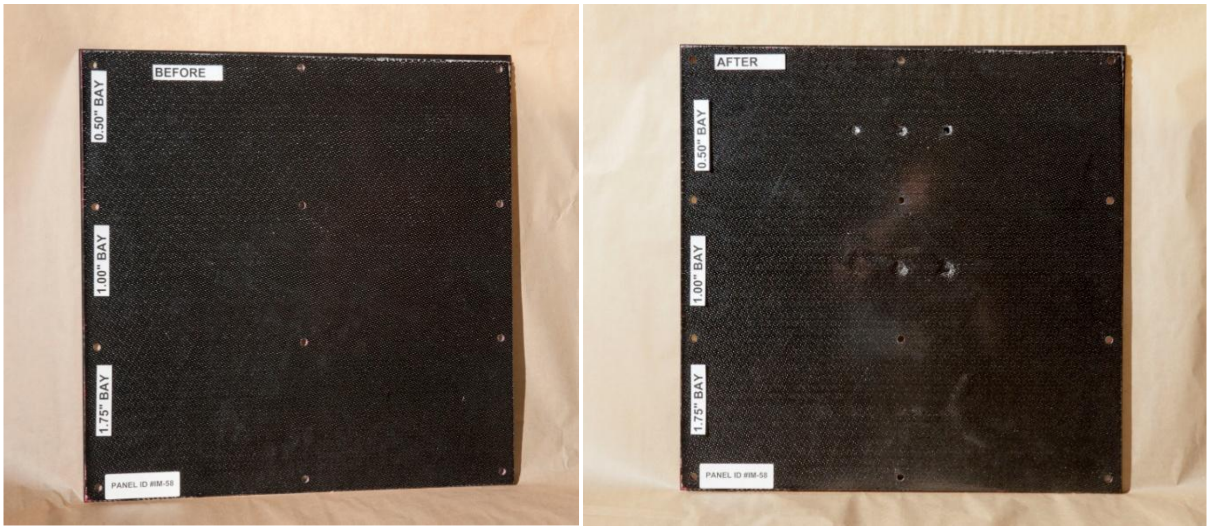


Figure D-120: Before and after pictures of front of panel IM-58.

Figure D-121: Before and after pictures of the back of panel IM-58.

Figure D-122: Side close up of front of panel IM-58.

Figure D-123: Side close up of back of panel IM-58.

Figure D-124: Before and after pictures of the front of panel IM-59.

Figure D-125: Before and after pictures of the back of panel IM-59.

Figure D-126: Before and after pictures of the front of panel IM-60.

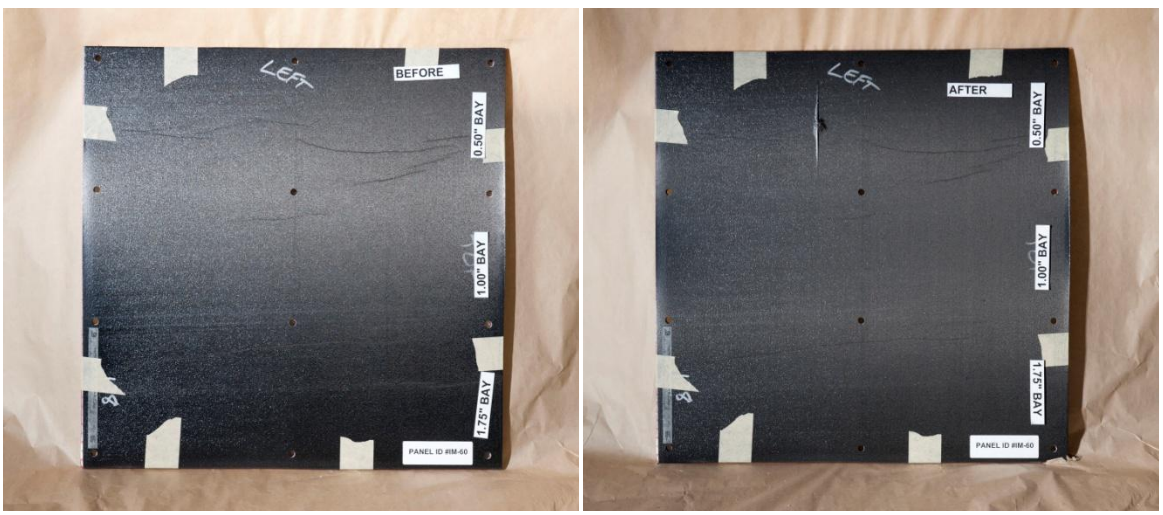


Figure D-127: Before and after pictures of the back of panel IM-60.

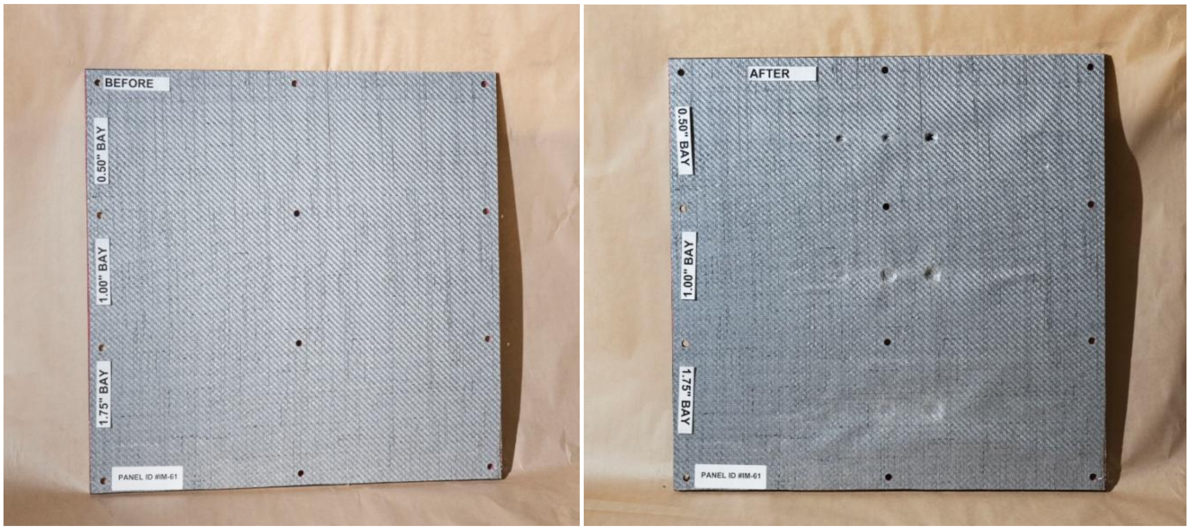


Figure D-128: Before and after pictures of the front of panel IM-61.

Figure D-129: Before and after pictures of the back of panel IM-61.

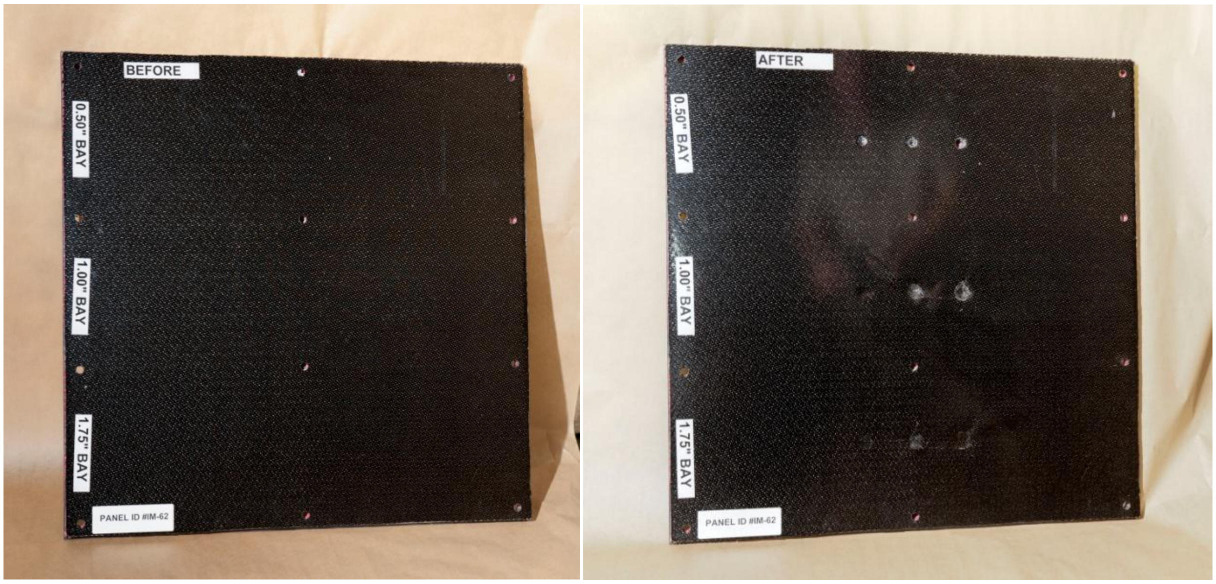


Figure D-130: Before and after pictures of the front of panel IM-62.

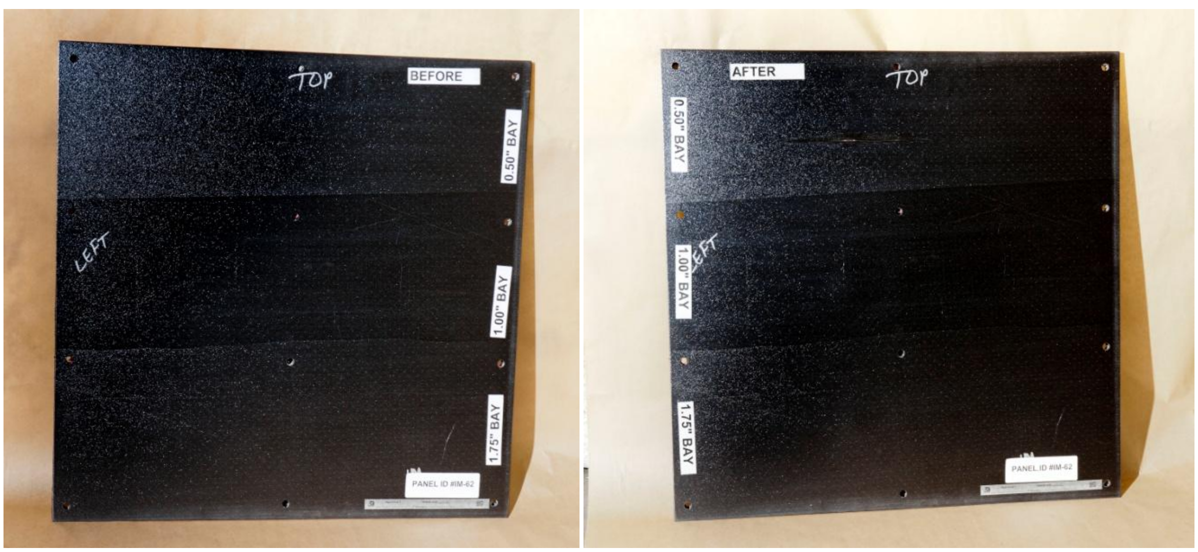


Figure D-131: Before and after pictures of the back of panel IM-62.

Figure D-132: Back of panel IM-62 after 250 in-lb with 0.5” impactor.

Figure D-133: Before and after pictures of the front of panel IM-63.

Figure D-134: Before and after pictures of the back of panel IM-63.

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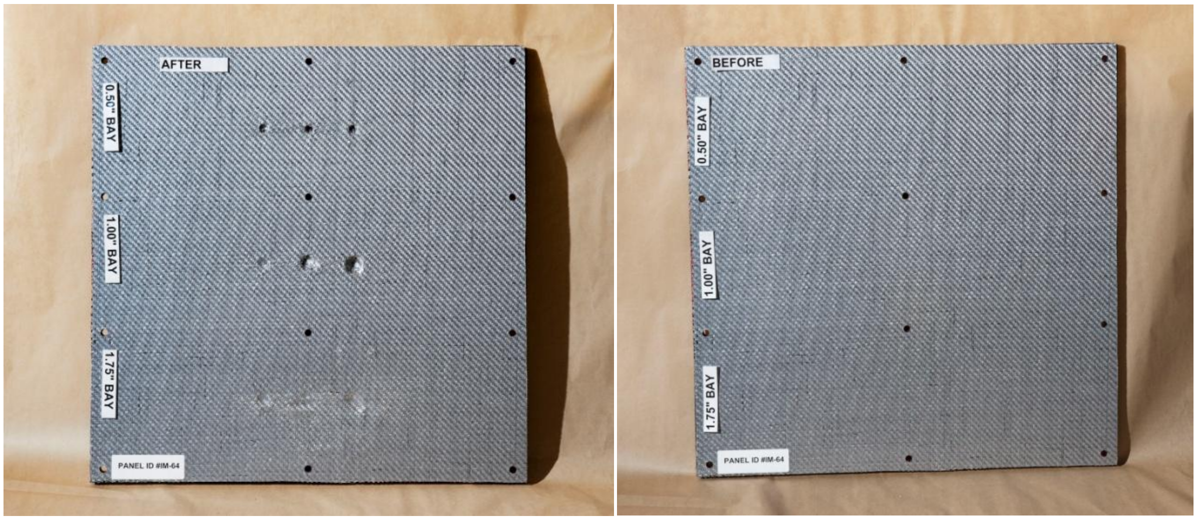


Figure D-135: Before and after pictures of the front of panel IM-64.

Figure D-136: Before and after pictures of the back of panel IM-64.

Figure D-137: Before and after pictures of the front of panel IM-65.

Figure D-138: Before and after pictures of the back of panel IM-65.

Figure D-139: Before and after pictures of the front of panel IM-66.

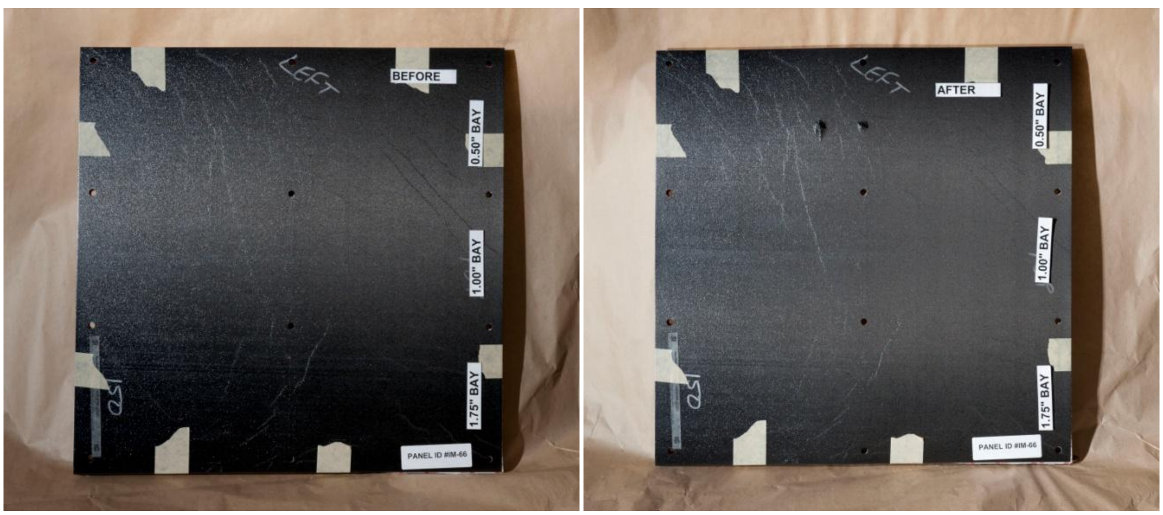


Figure D-140: Before and after pictures of the back of panel IM-66.

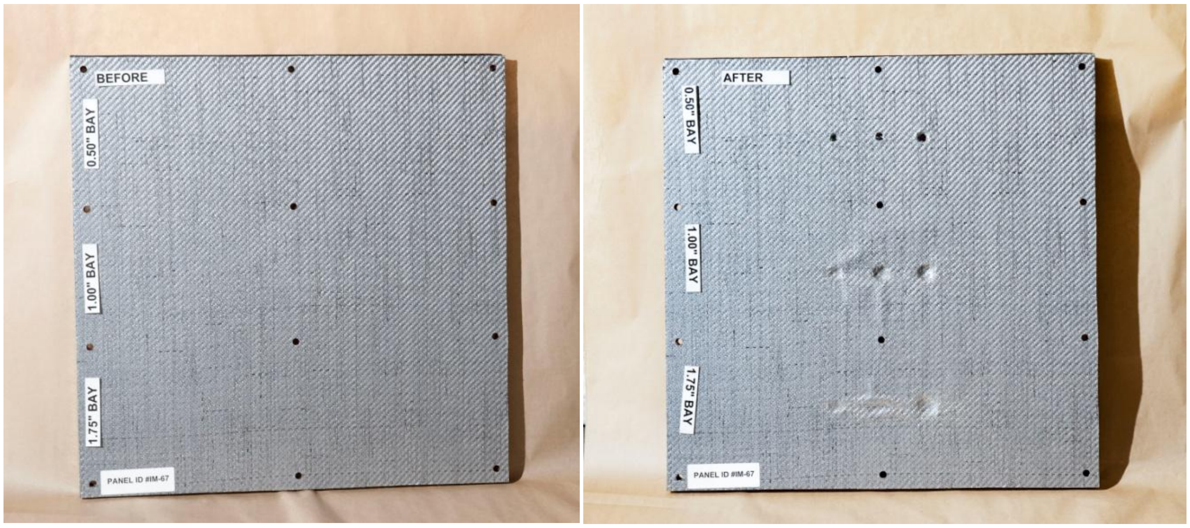


Figure D-141: Before and after pictures of the front of panel IM-67.

Figure D-142: Before and after pictures of the back of panel IM-67.

Figure D-143: Before and after pictures of the front of panel IM-68.

Figure D-144: Before and after pictures of the back of panel IM-68.

Figure D-145: Side view of front of panel IM-68 after impact.

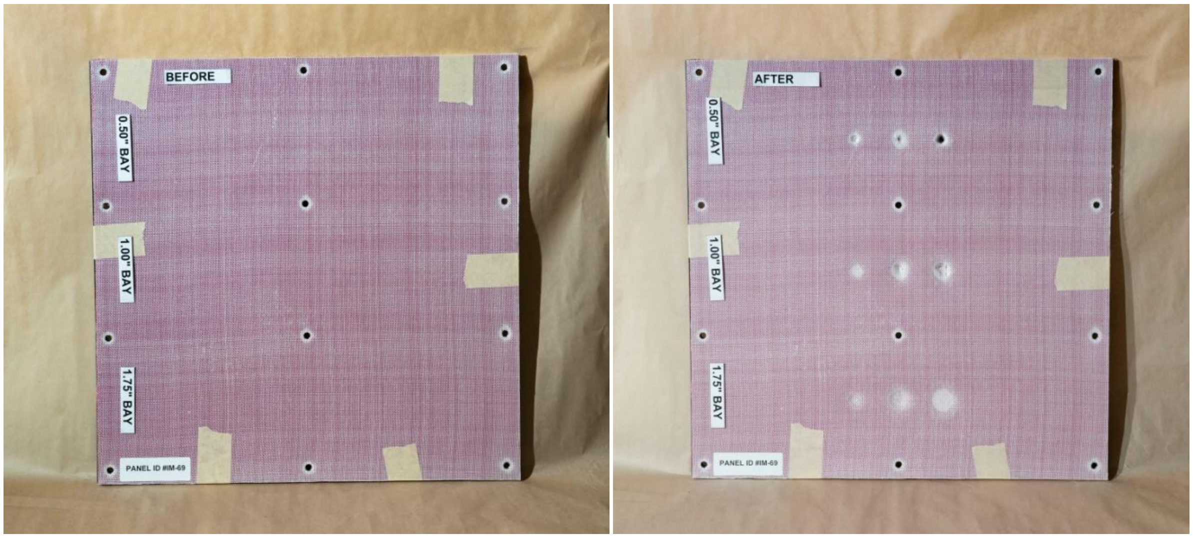


Figure D-146: Before and after pictures of the front of panel IM-69.

Figure D-147: Before and after pictures of the back of panel IM-69.

Figure D-148: Before and after pictures of the front of panel IM-70.

Figure D-149: Before and after pictures of the back of panel IM-70.

Figure D-150: Before and after pictures of the front of panel IM-71.

Figure D-151: Before and after pictures of the back of panel IM-71.

Figure D-152: Side view of the back of panel IM-71 after impact.

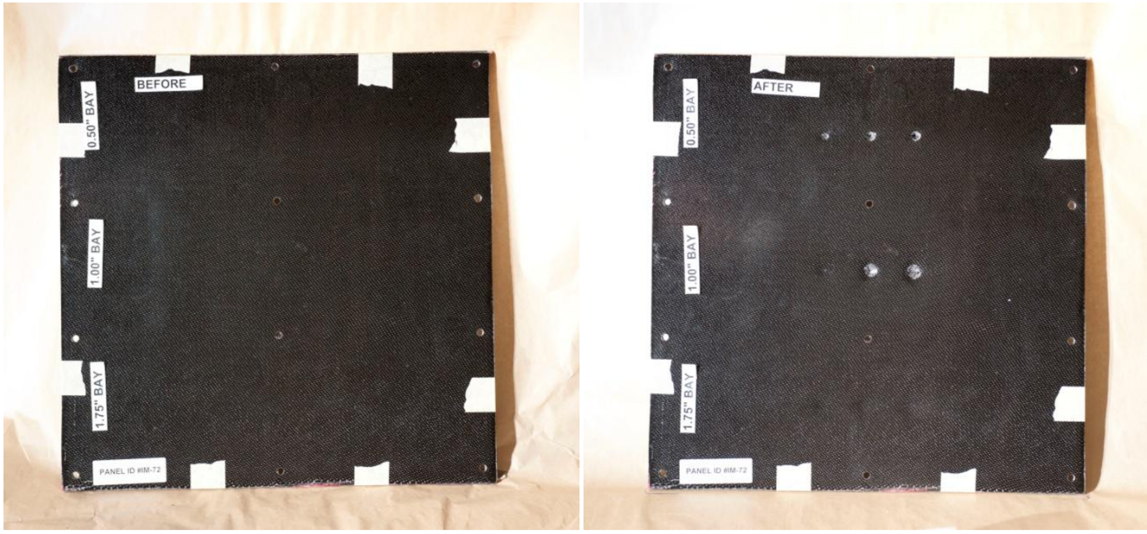


Figure D-153: Before and after pictures of the front of panel IM-72.

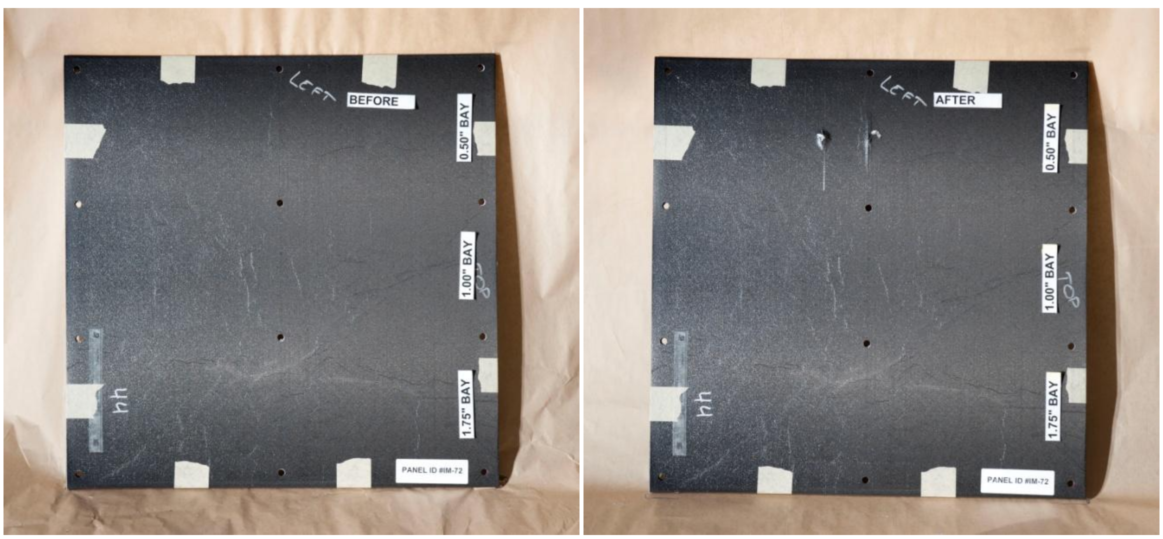


Figure D-154: Before and after pictures of the back of panel IM-72.

Figure D-155: Before and after pictures of the front of panel IM-73.

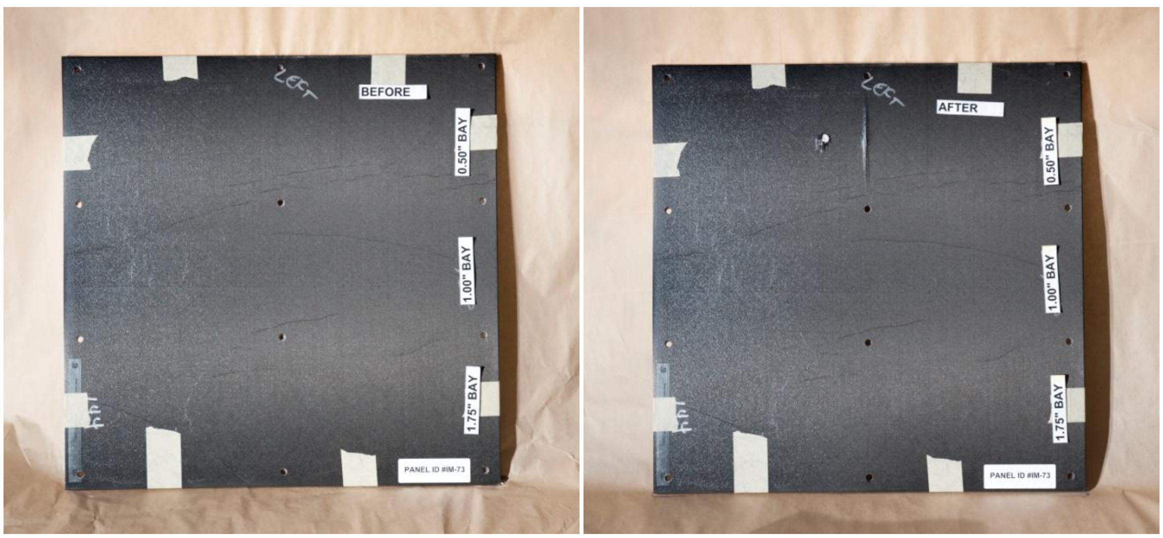


Figure D-156: Before and after pictures of the back of panel IM-73.

Figure D-157: Before and after pictures of the front of panel IM-74.

Figure D-158: Before and after pictures of the back of panel IM-74.

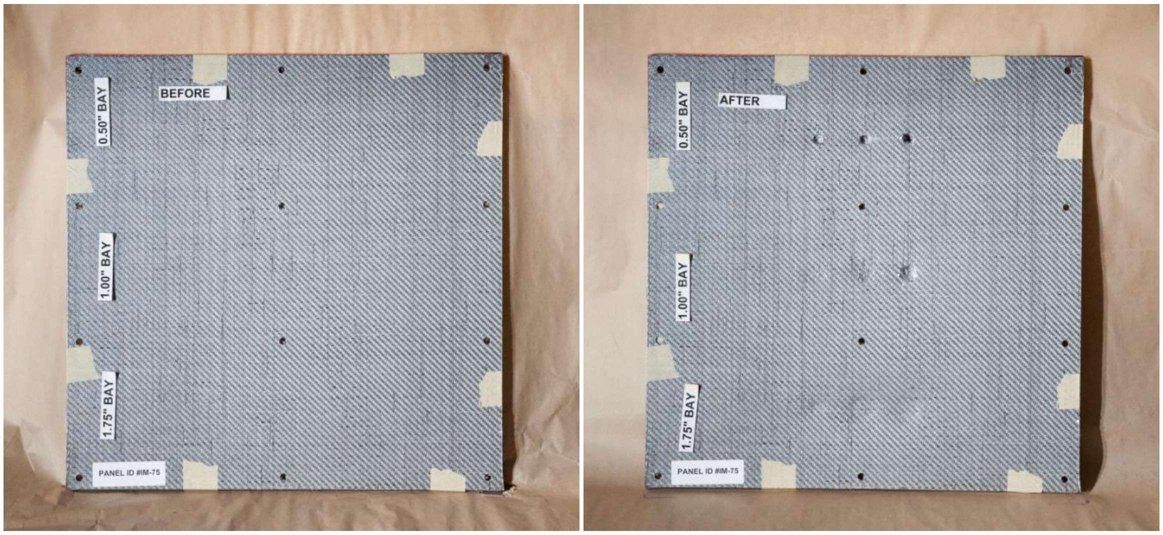


Figure D-159: Before and after pictures of the front of panel IM-75.

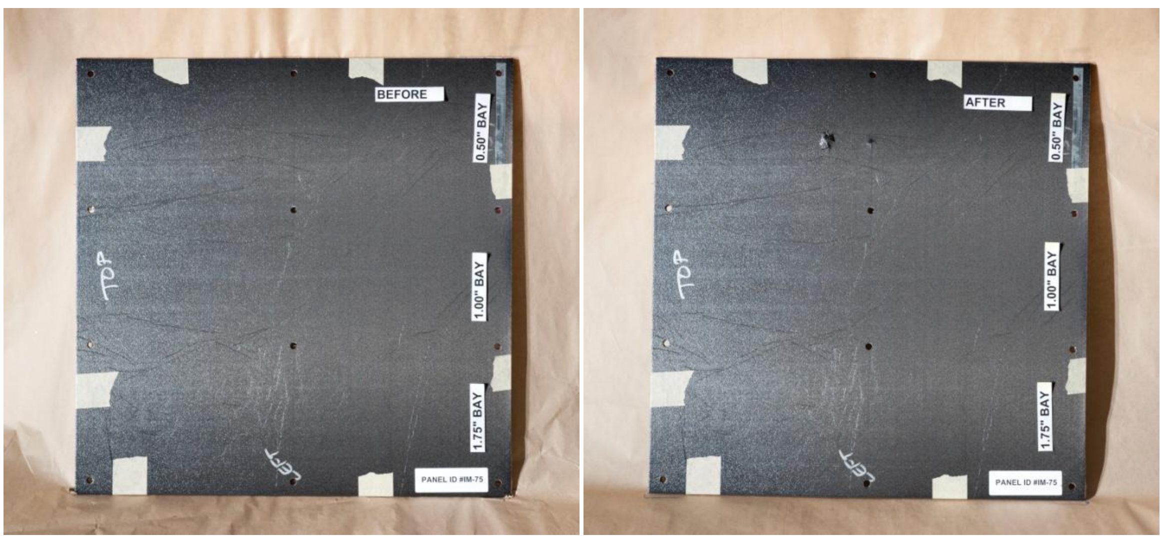


Figure D-160: Before and after pictures of the back of panel IM-75.

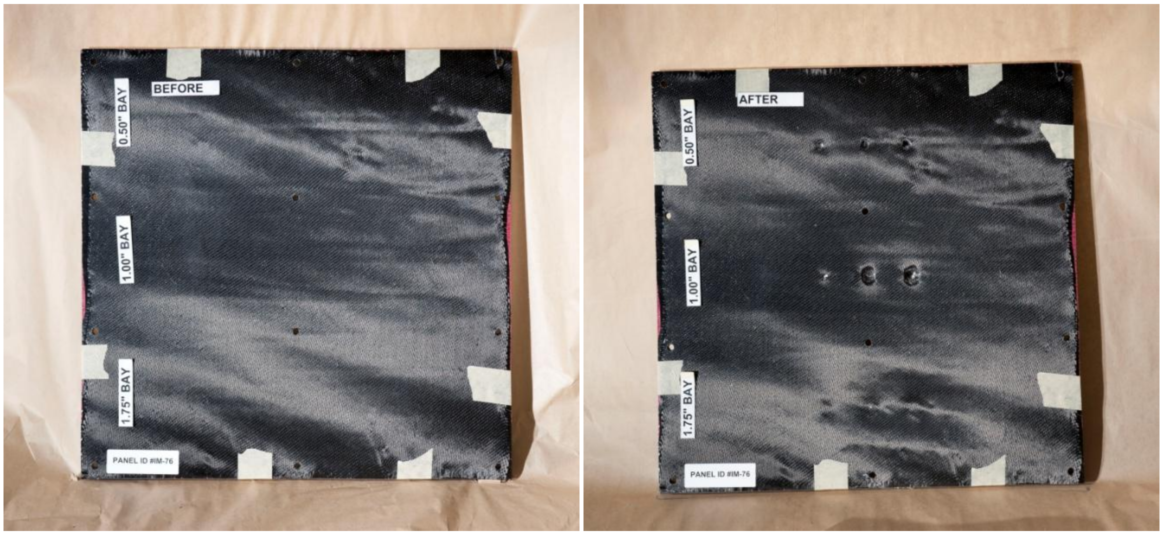


Figure D-161: Before and after pictures of the front of panel IM-76.

Figure D-162: Before and after pictures of the back of panel IM-76.

Figure D-163: Before and after pictures of the front of panel IM-77.

Figure D-164: Before and after pictures of the back of panel IM-77.

Figure D-165: Before and after pictures of the front of panel IM-78.

Figure D-166: Before and after pictures of the back of panel IM-78.

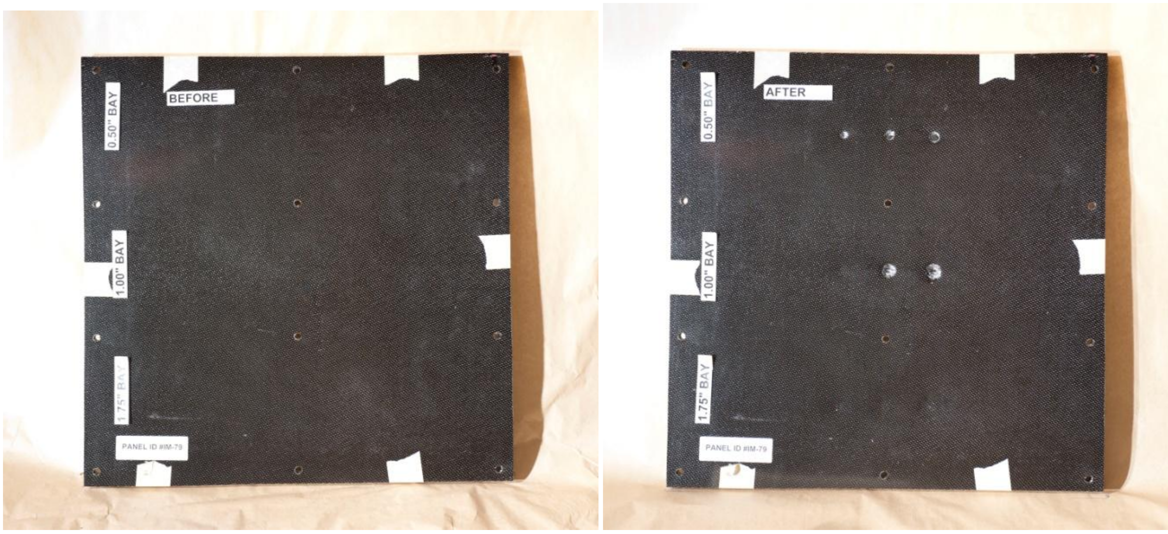


Figure D-167: Before and after pictures of the front of panel IM-79.

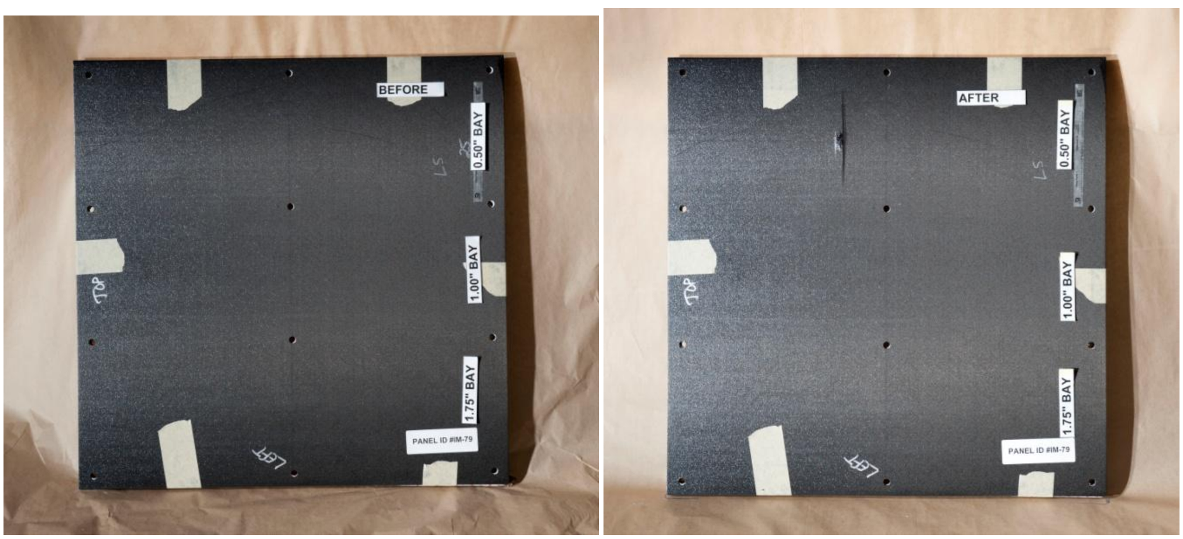


Figure D-168: Before and after pictures of the back of panel IM-79.

Figure D-169: Before and after pictures of the front of panel IM-80.

Figure D-170: Before and after pictures of the back of panel IM-80.

Figure D-171: Before and after pictures of the front of panel IM-81.

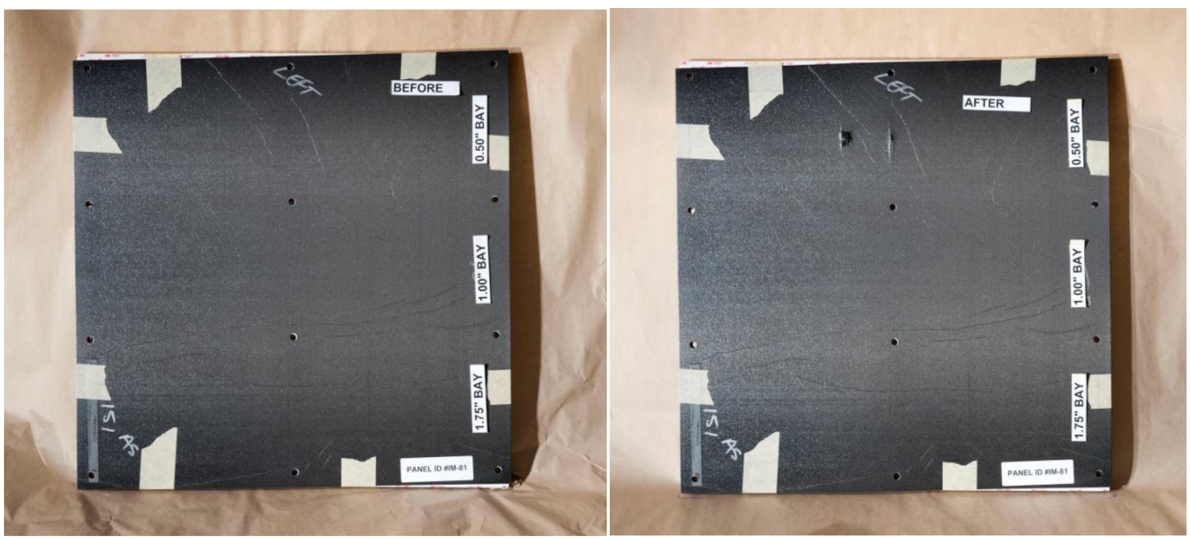


Figure D-172: Before and after pictures of the back of panel IM-81.

Figure D-173: Before and after pictures of the front of panel IM-82.

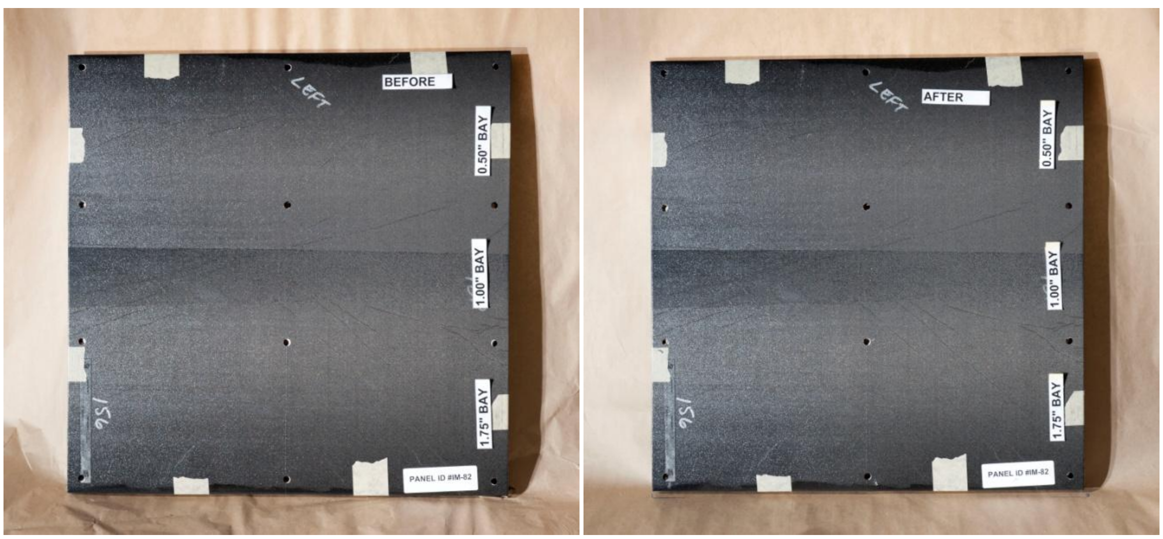


Figure D-174: Before and after pictures of the back of panel IM-82.

Figure D-175: Before and after pictures of the front of panel IM-83.

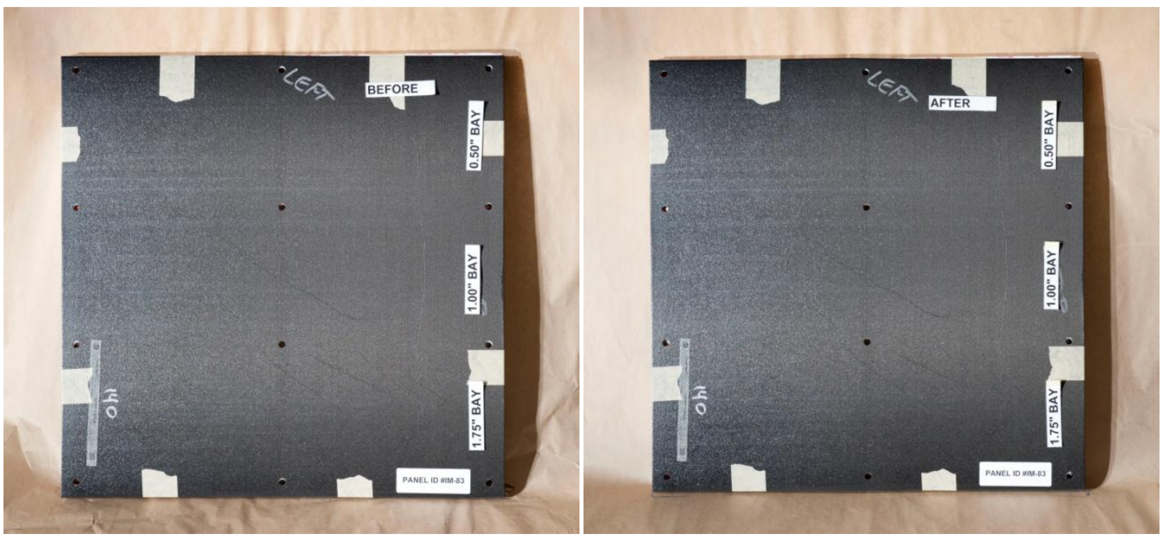


Figure D-176: Before and after pictures of the back of panel IM-83.

Figure D-177: Before and after pictures of the front of panel IM-84.

Figure D-178: Before and after pictures of the back of panel IM-84.

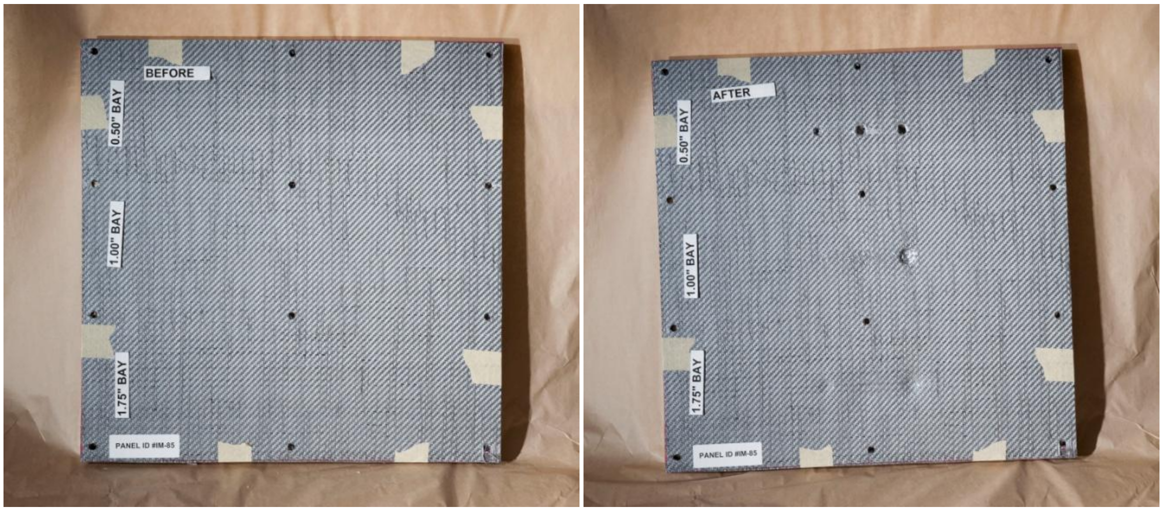


Figure D-179: Before and after pictures of the front of panel IM-85.

Figure D-180: Before and after pictures of the back of panel IM-85.

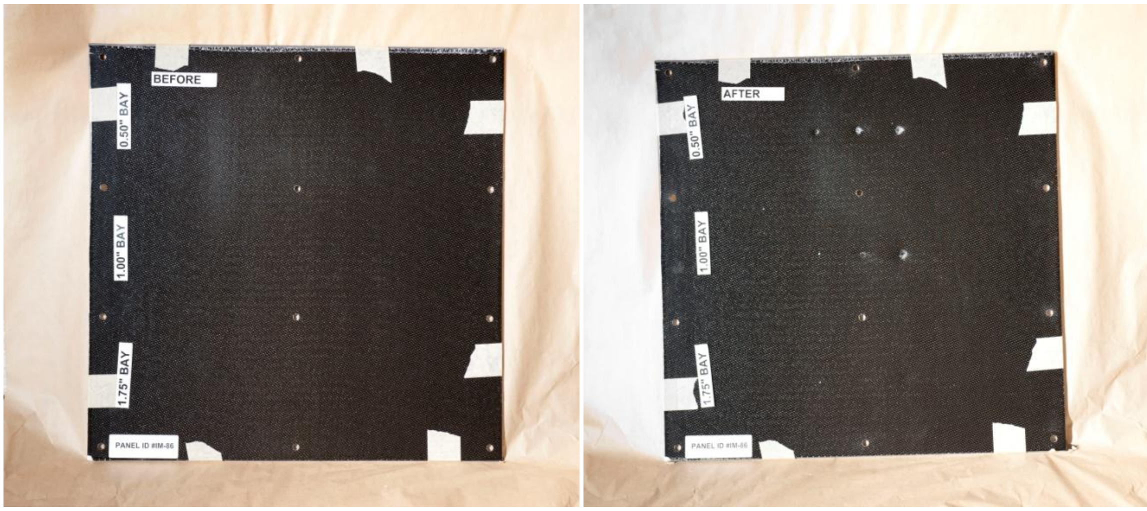


Figure D-181: Before and after pictures of the front of panel IM-86.

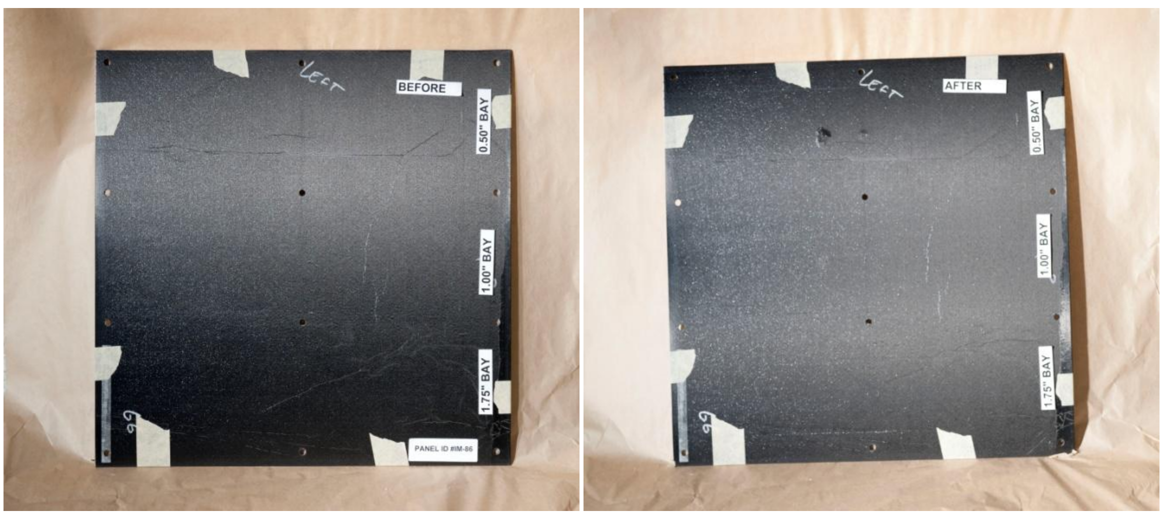


Figure D-182: Before and after pictures of the back of panel IM-86.

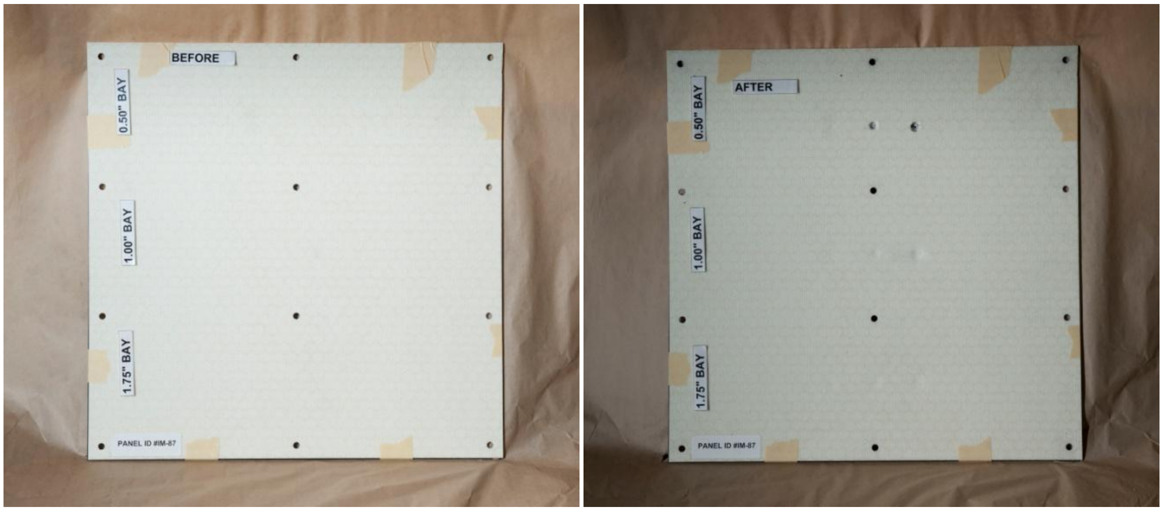


Figure D-183: Before and after pictures of the front of panel IM-87.

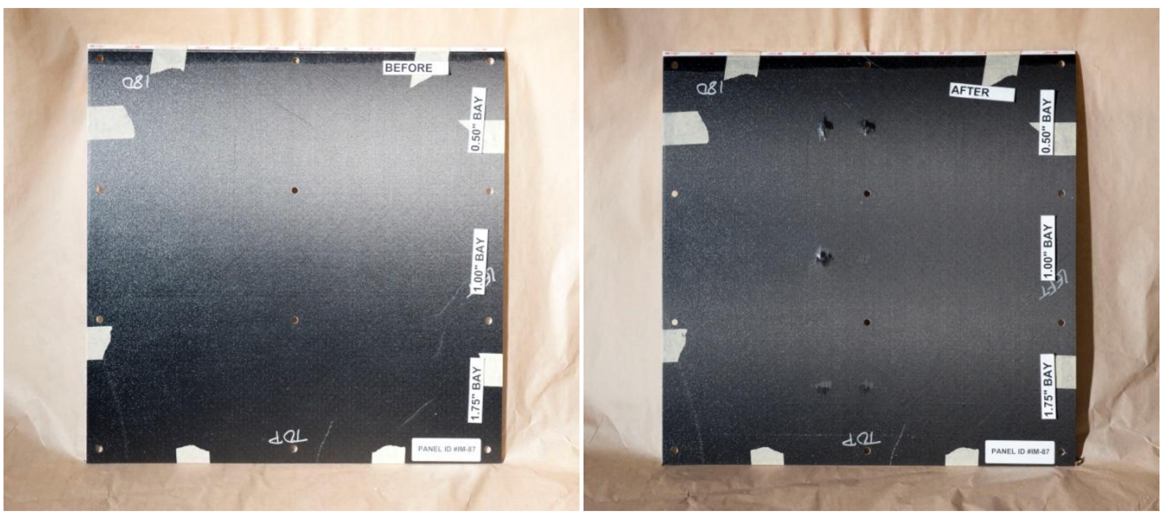


Figure D-184: Before and after pictures of the back of panel IM-87.

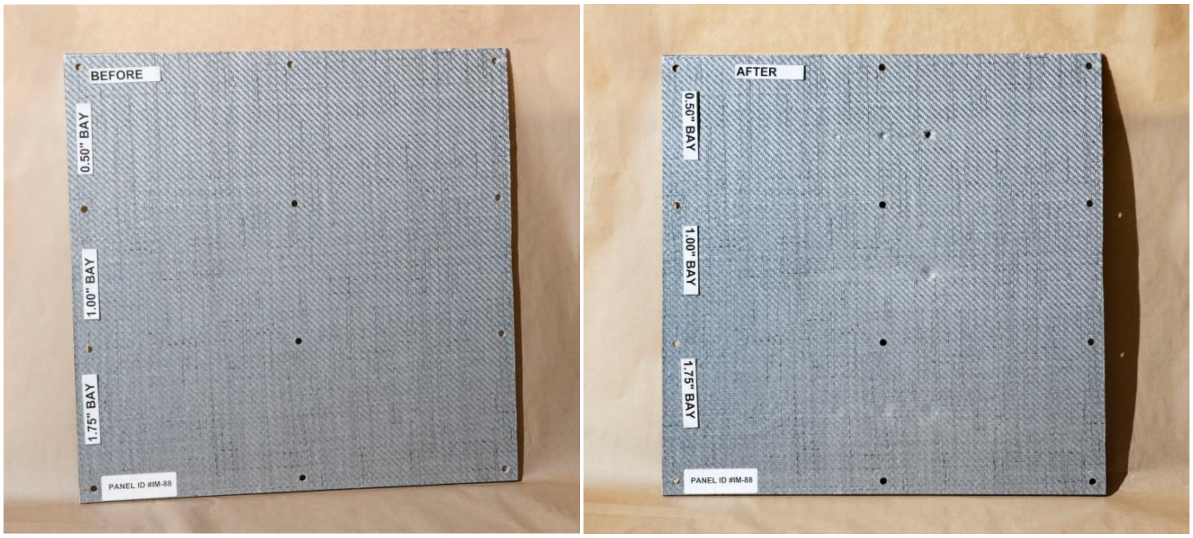


Figure D-185: Before and after pictures of the front of panel IM-88.

Figure D-186: Before and after pictures of the back of panel IM-88.

Figure D-187: Before and after pictures of the front of panel IM-89.

Figure D-188: Before and after pictures of the back of panel IM-89.

Figure D-189: Side view of the back of panel IM-89 after impact.

Figure D-190: Before and after pictures of the front of panel IM-90.

Figure D-191: Before and after pictures of the back of panel IM-90.

Figure D-192: Before and after pictures of the front of panel IM-91.

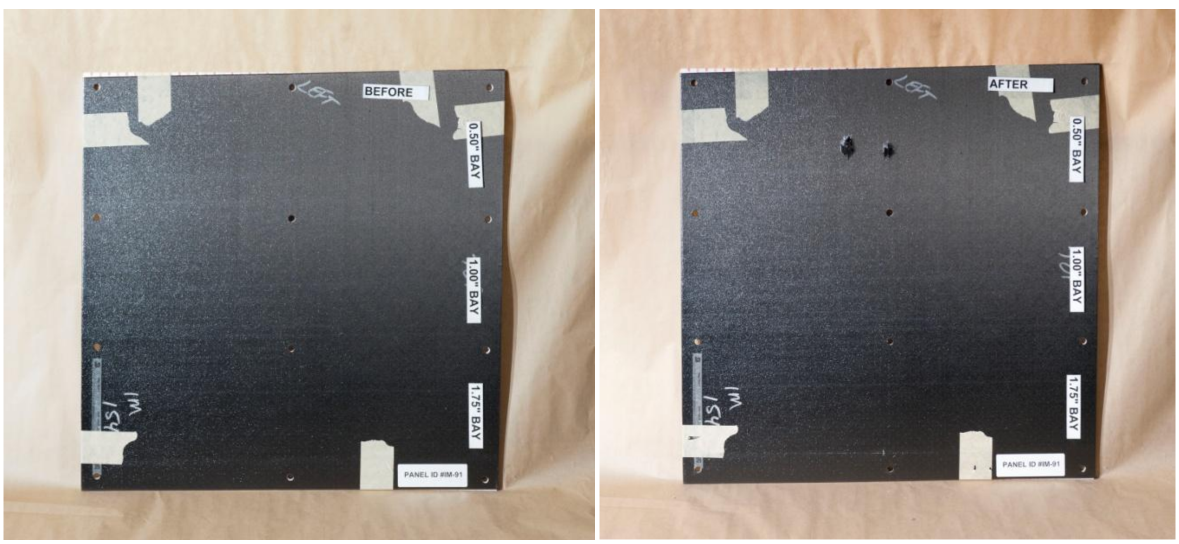


Figure D-193: Before and after pictures of the back of panel IM-91.

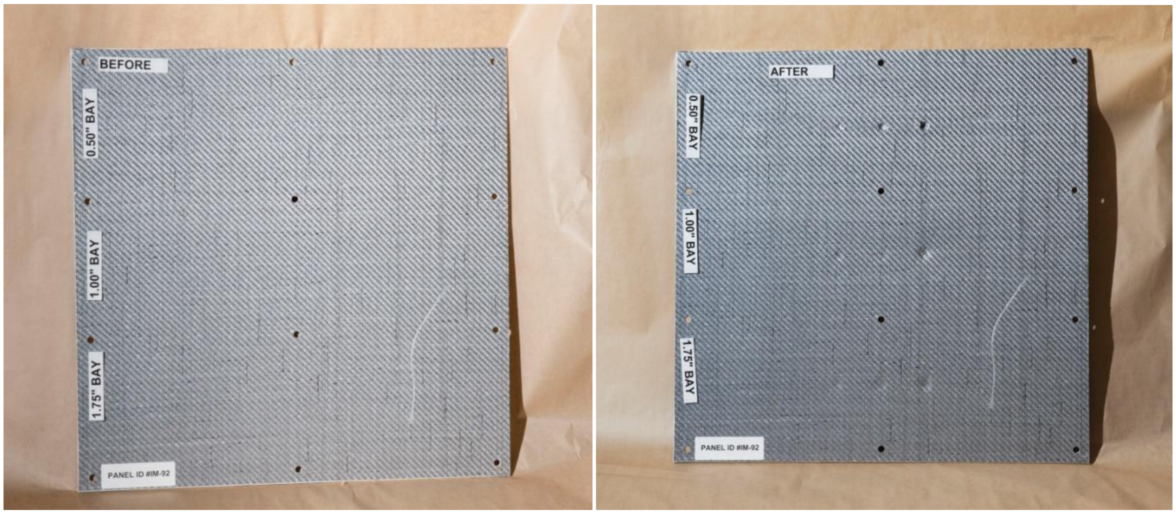


Figure D-194: Before and after pictures of the front of panel IM-92.

Figure D-195: Before and after pictures of the back of panel IM-92.

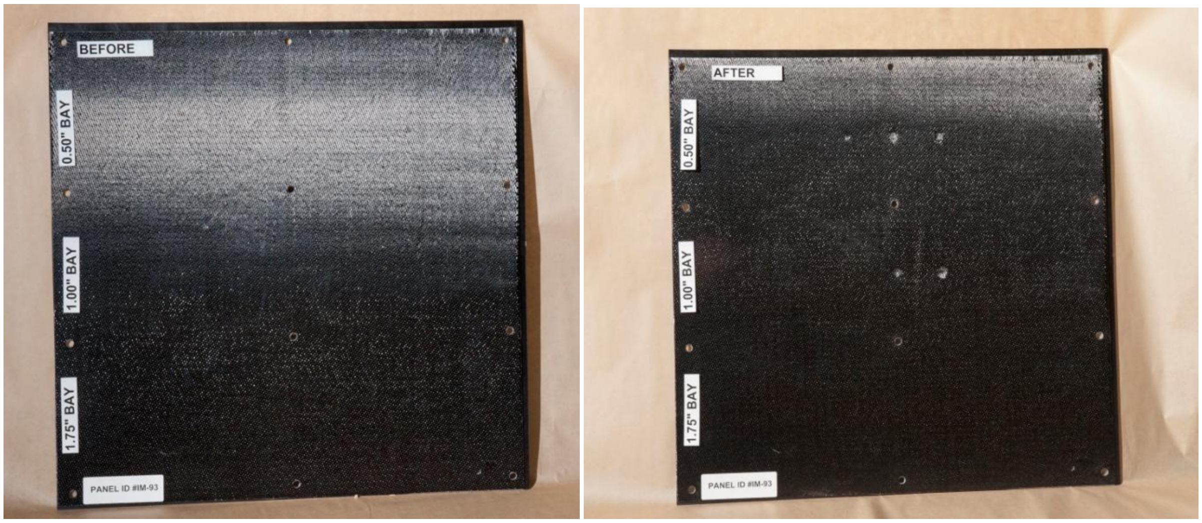


Figure D-196: Before and after pictures of the front of panel IM-93.

Figure D-197: Before and after pictures of the back of panel IM-93.

Figure D-198: Side view of back of panel IM-93 after impact.

Figure D-199: Before and after pictures of the front of panel IM-94.

Figure D-200: Before and after pictures of back of panel IM-94.

Figure D-201: Side view of back of panel IM-94 after impacts.

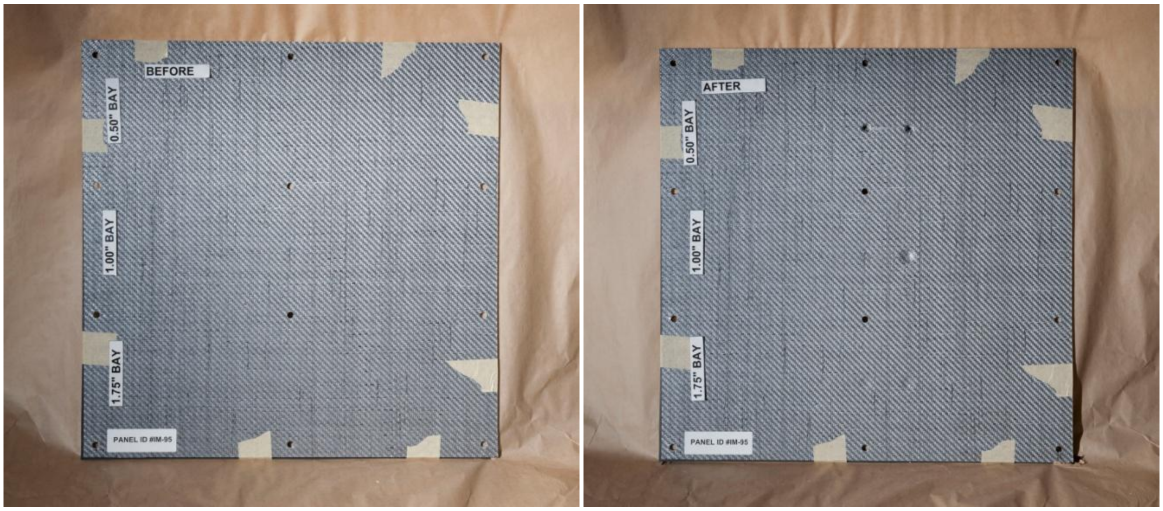


Figure D-202: Before and after pictures of the front of panel IM-95.

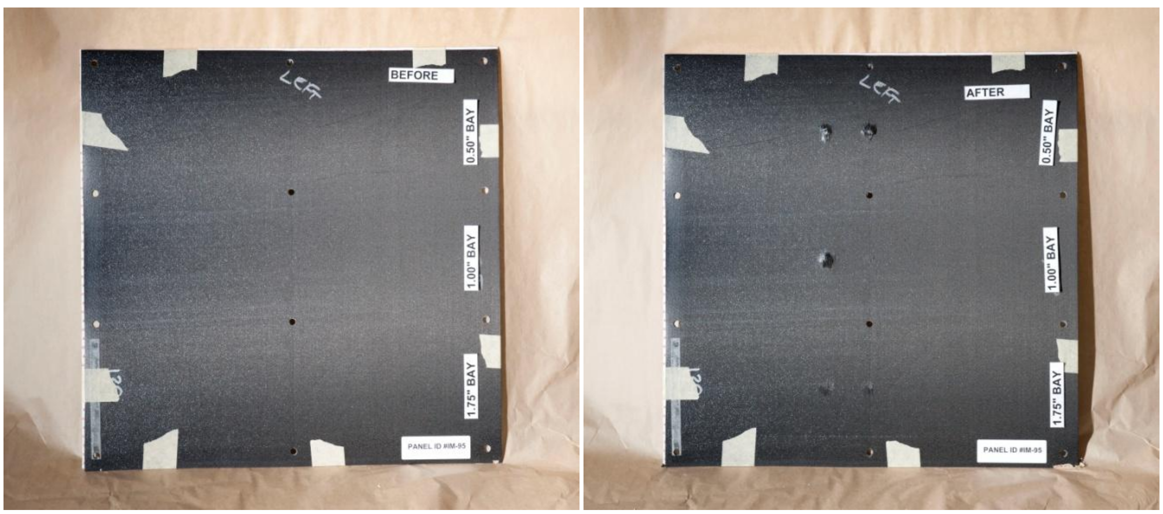


Figure D-203: Before and after pictures of the back of panel IM-95.

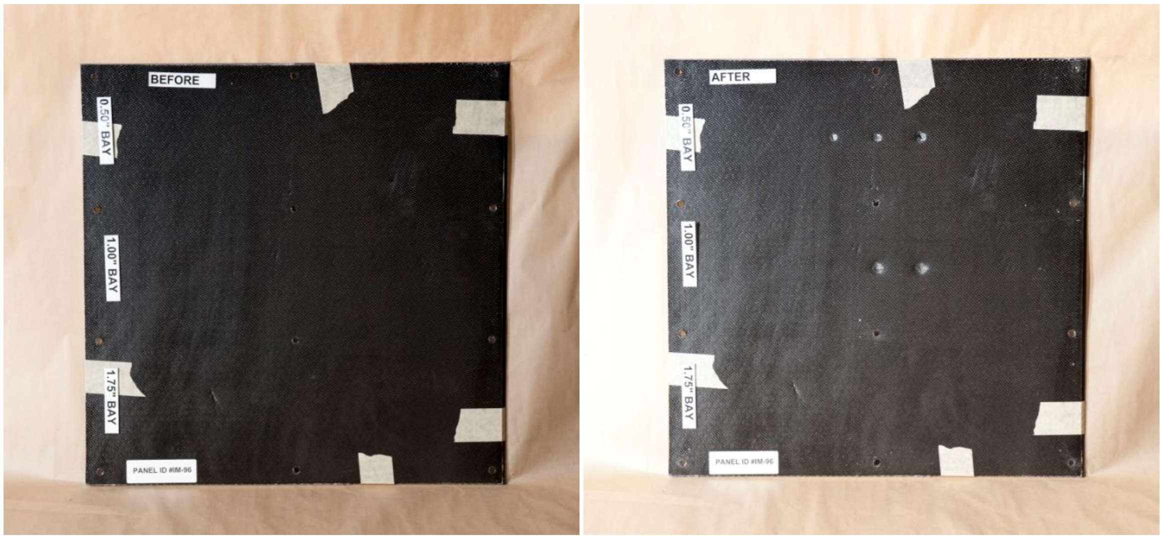


Figure D-204: Before and after pictures of the front of panel IM-96.

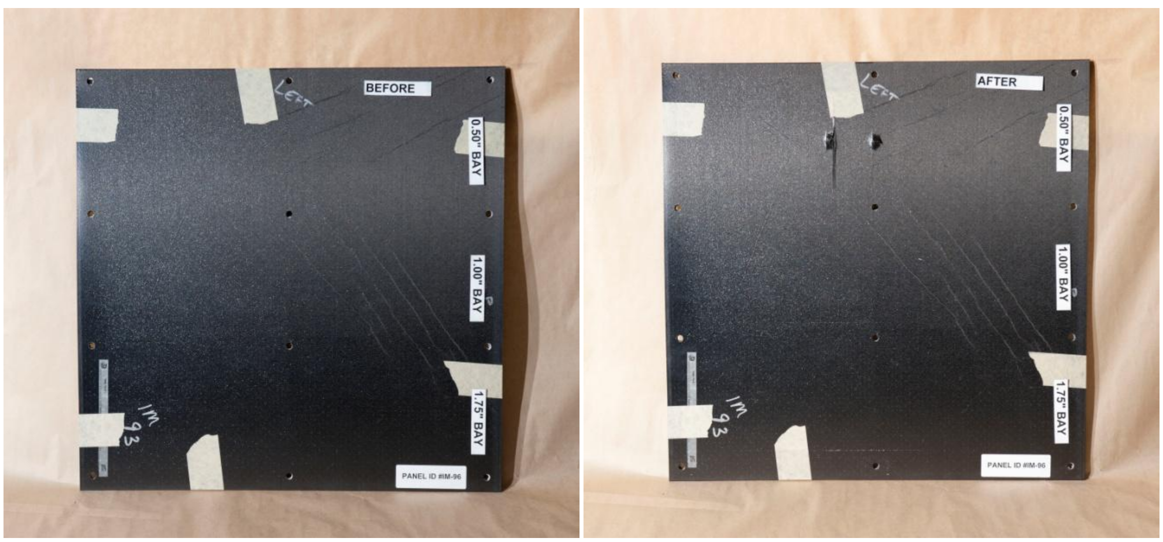


Figure D-205: Before and after pictures of the back of panel IM-96.

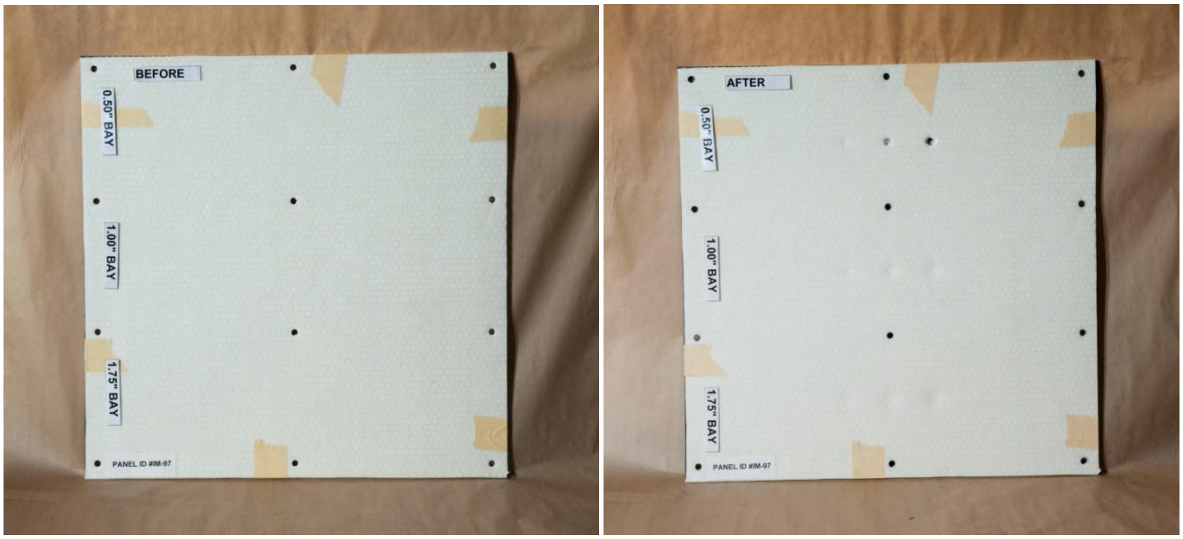


Figure D-206: Before and after pictures of the front of panel IM-97.

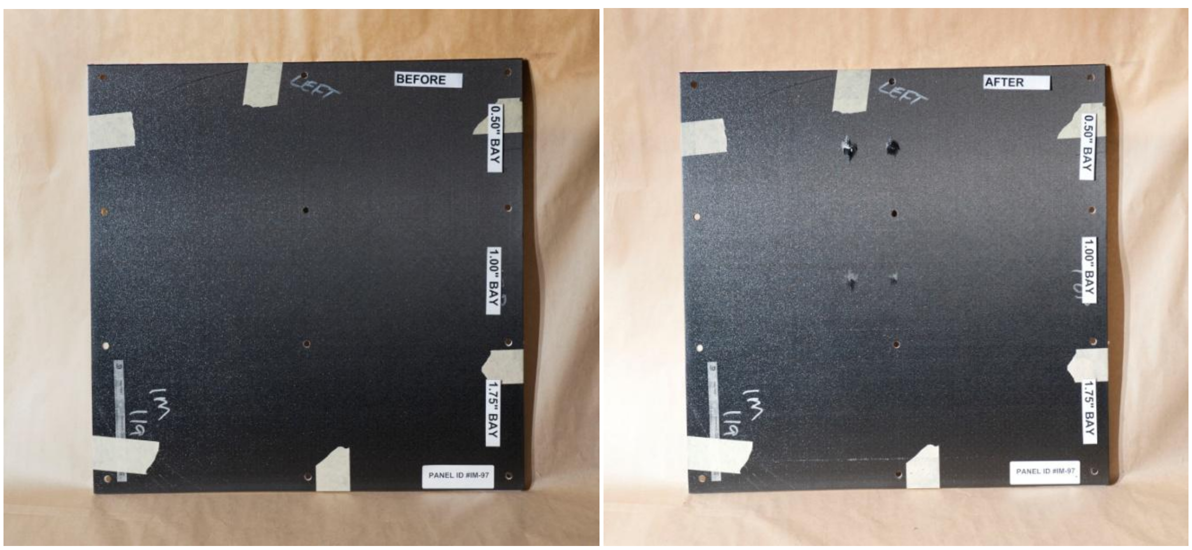


Figure D-207: Before and after pictures of the back of panel IM-97.

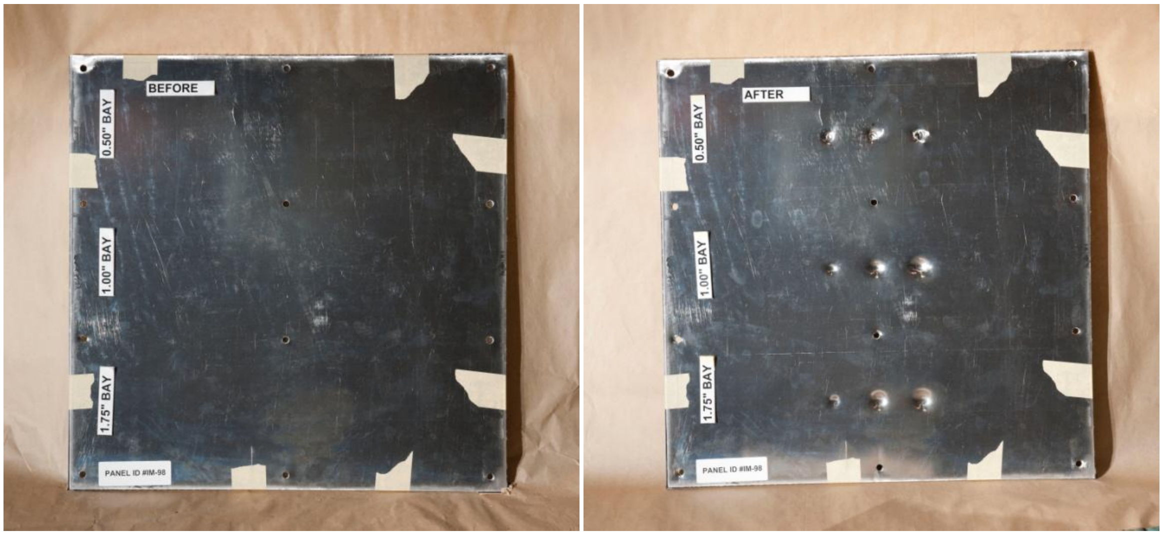


Figure D-208: Before and after pictures of the front of panel IM-98.

Figure D-209: Before and after pictures of the back of panel IM-98.

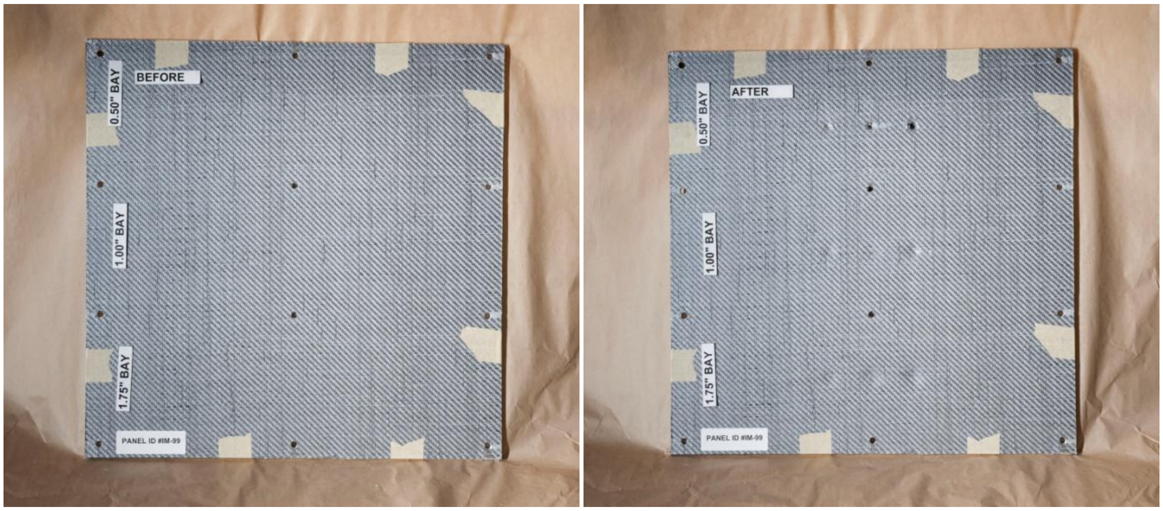


Figure D-210: Before and after pictures of the front of panel IM-99.

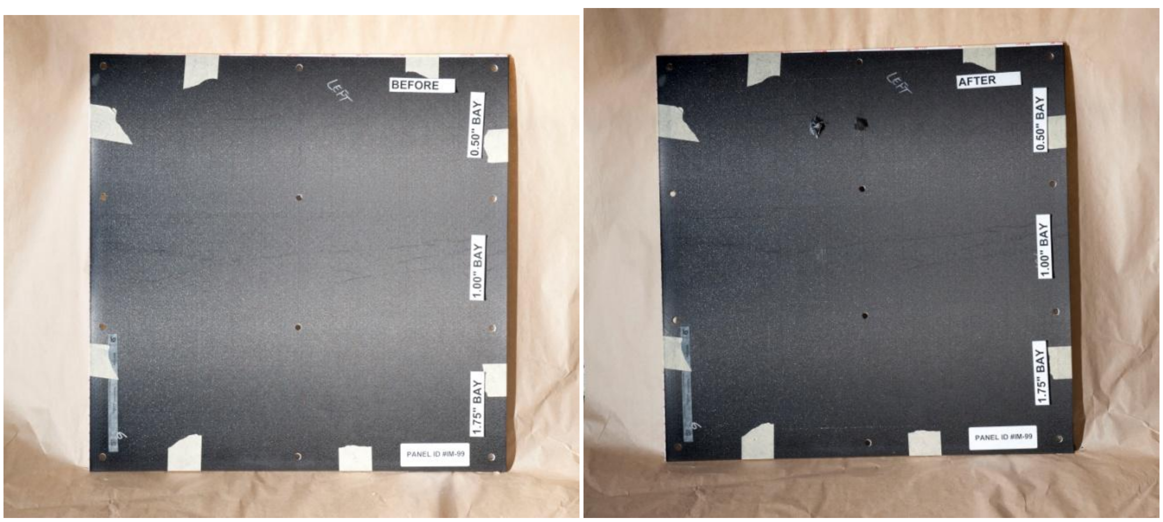


Figure D-211: Before and after pictures of the back of panel IM-99.

Figure D-212: Before and after pictures of the front of panel IM-100.

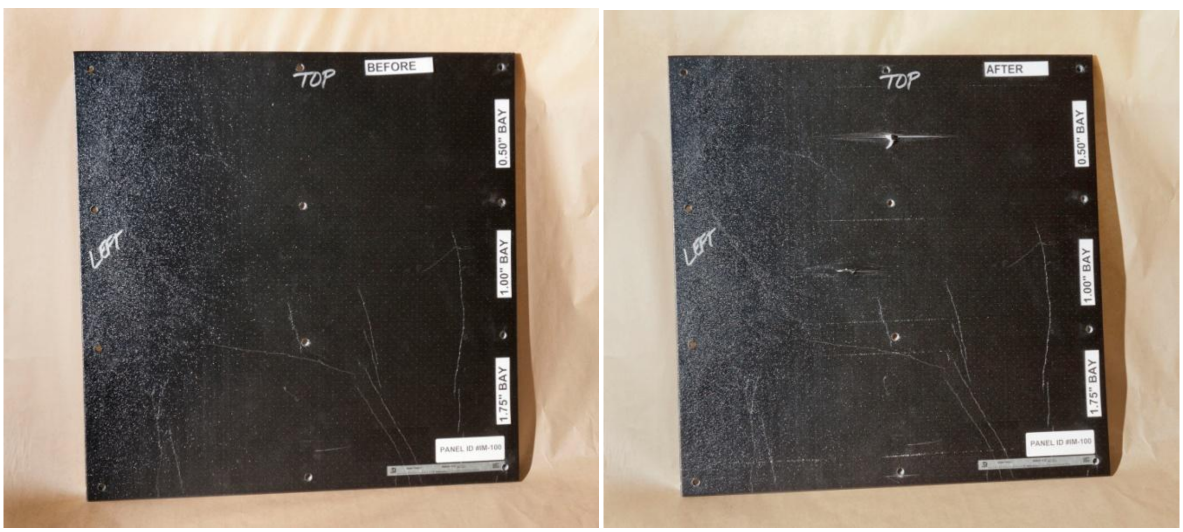


Figure D-213: Before and after pictures of the back of panel IM-100.

Figure D-214: 1.0" impactor penetrating panel after 180 in-lb impact (top side and bottom view).

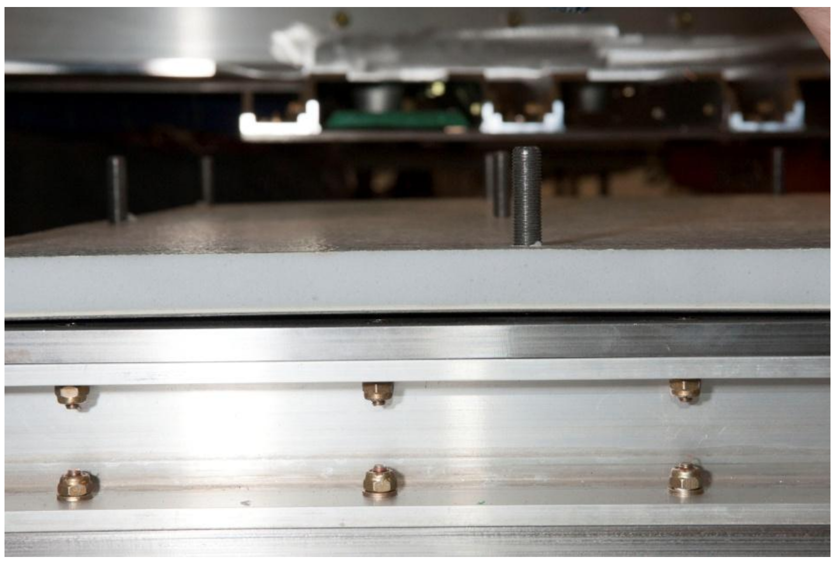


Figure D-215: Panel IM-100 installed on test platform.

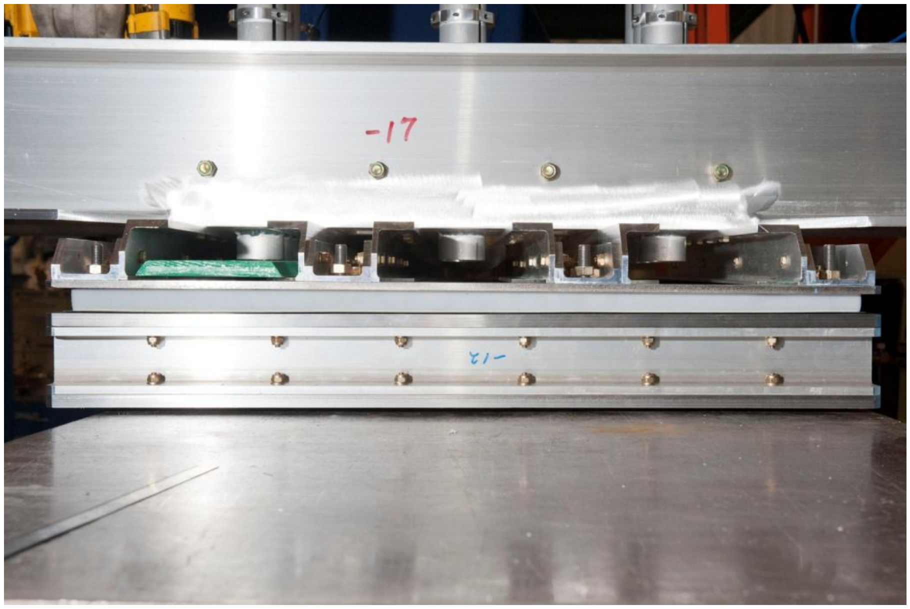


Figure D-216: Panel IM-100 installed in test facility.

Appendix E -
First-Generation Shielding Effectiveness Test Setup

Figure E-1: Top hat antenna in the main chamber.

Figure E-2: Top hat antenna in the main chamber.

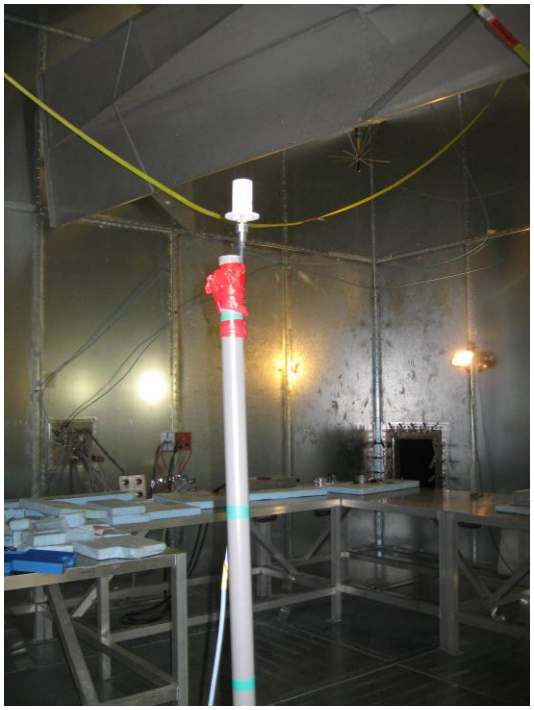


Figure E-3: Top hat antenna in the main chamber.

Figure E-4: Main reverberation chamber.

Figure E-5: Top hat antenna in the main chamber.

Figure E-6: Top hat antenna in the shielded room.

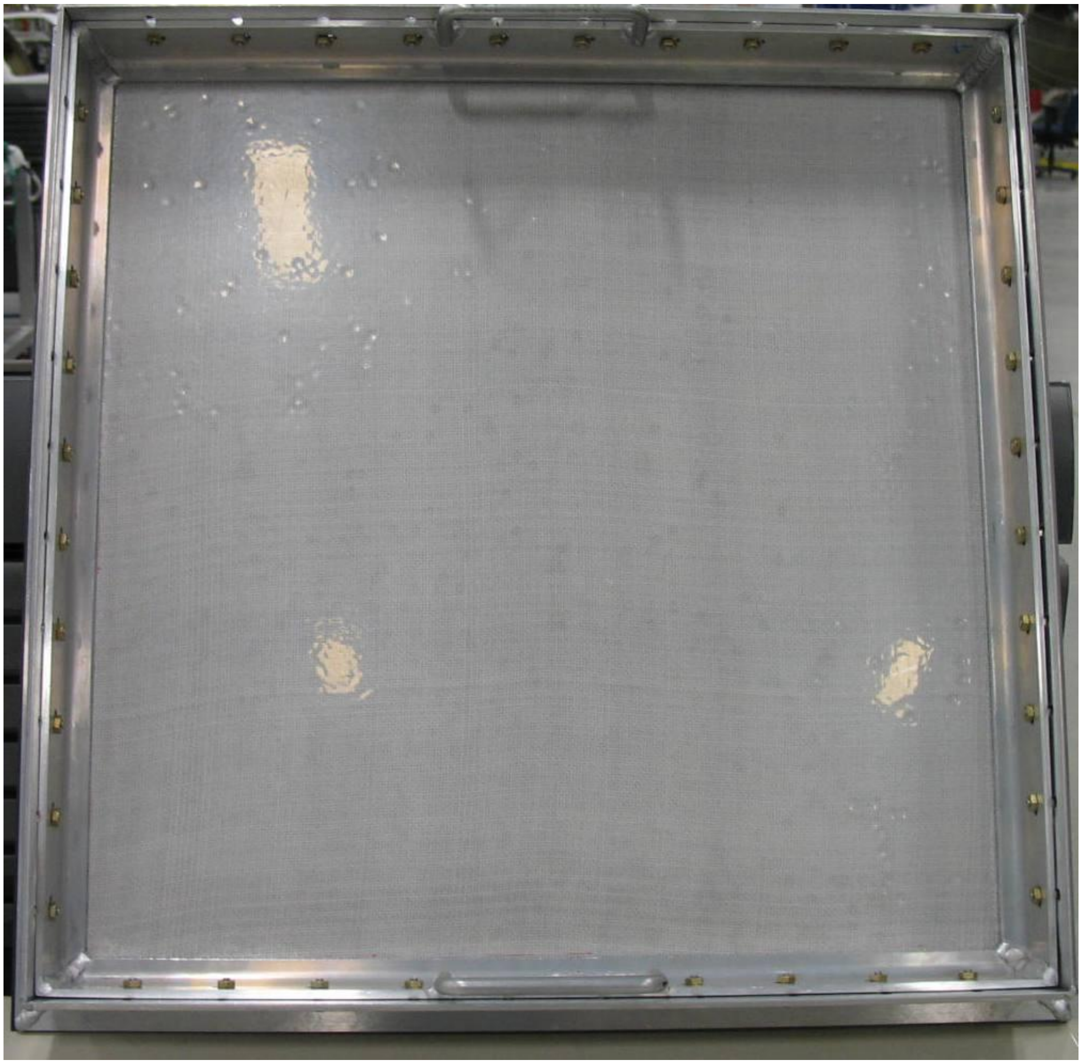


Figure E- 7: Panel mounted in transmissivity frame.

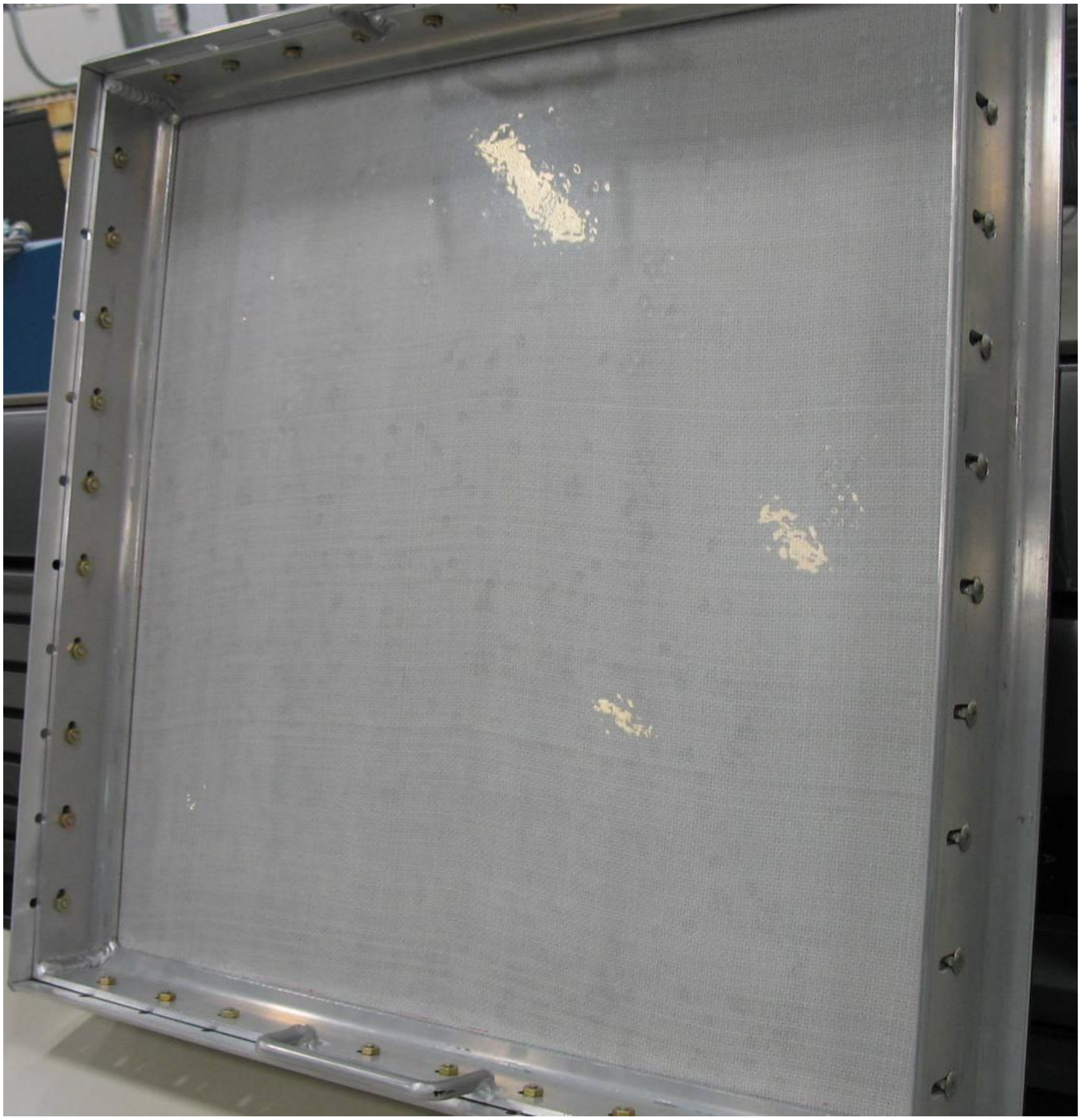


Figure E-8: Side view of panel mounted in transmissivity frame.

Figure E-9: Aluminum panel mounted in test chamber.

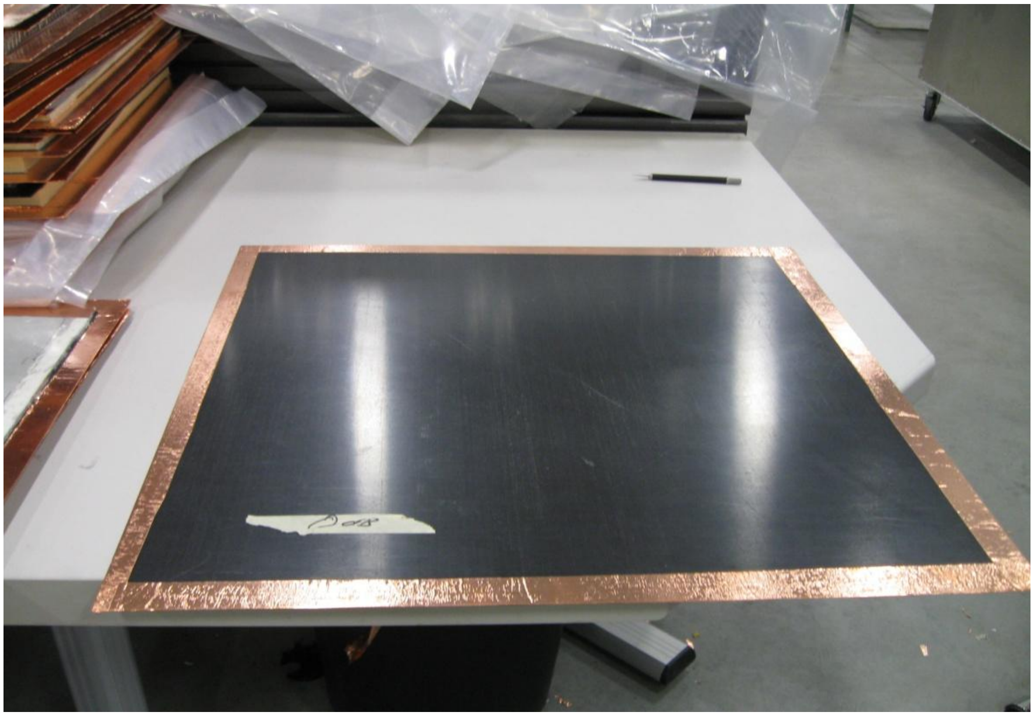


Figure E-10: Bare CFC (carbon fiber composite) panel (no lightning strike protection).

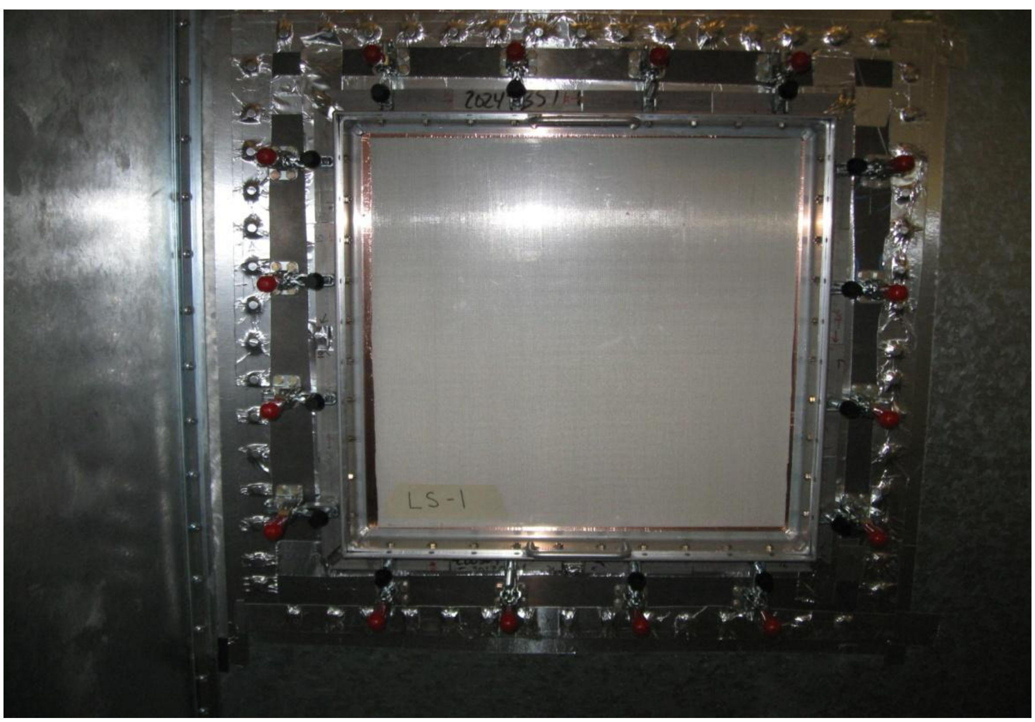


Figure E-11: Panel LS-1 mounted in chamber.

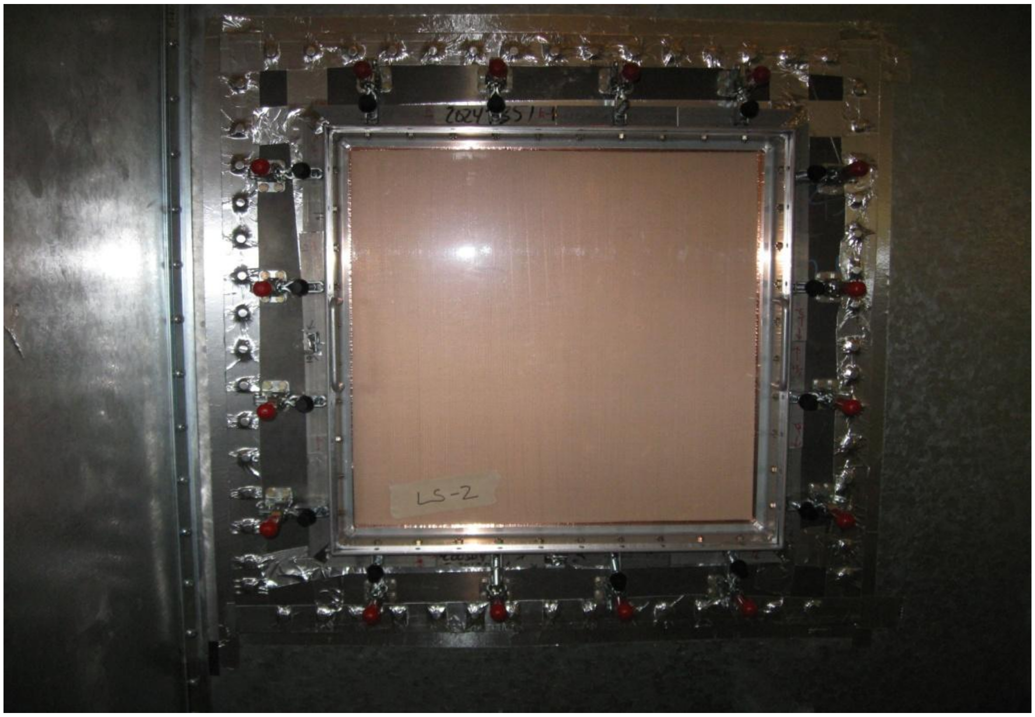


Figure E-12: Panel LS-2 mounted in chamber.

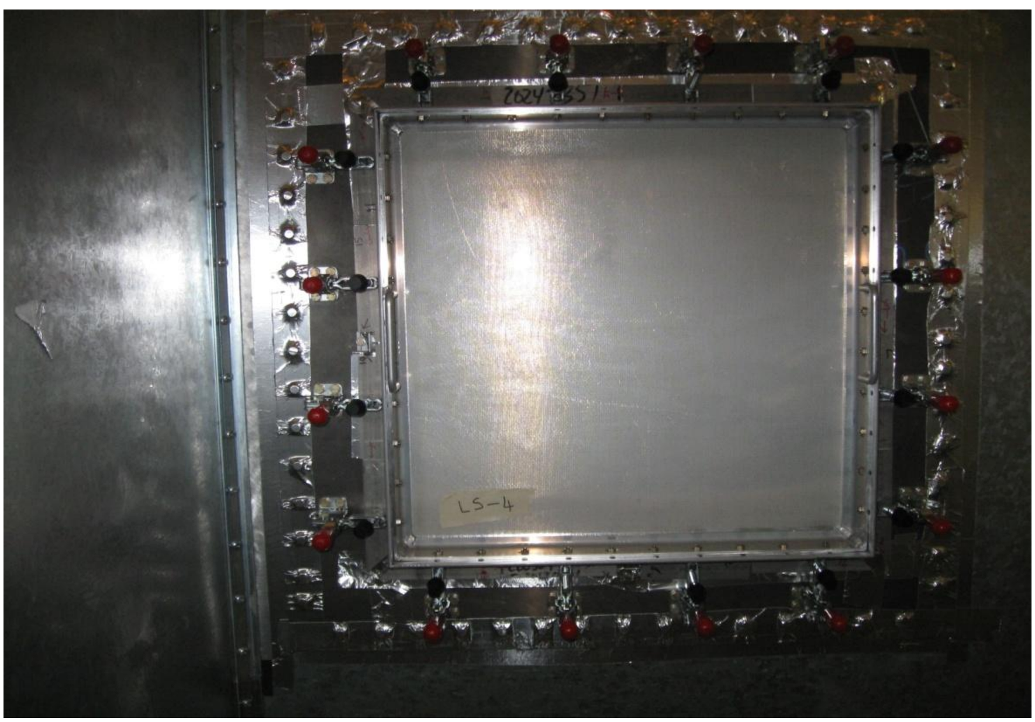


Figure E-13: Panel LS-4 mounted in chamber (without copper tape on top of core).

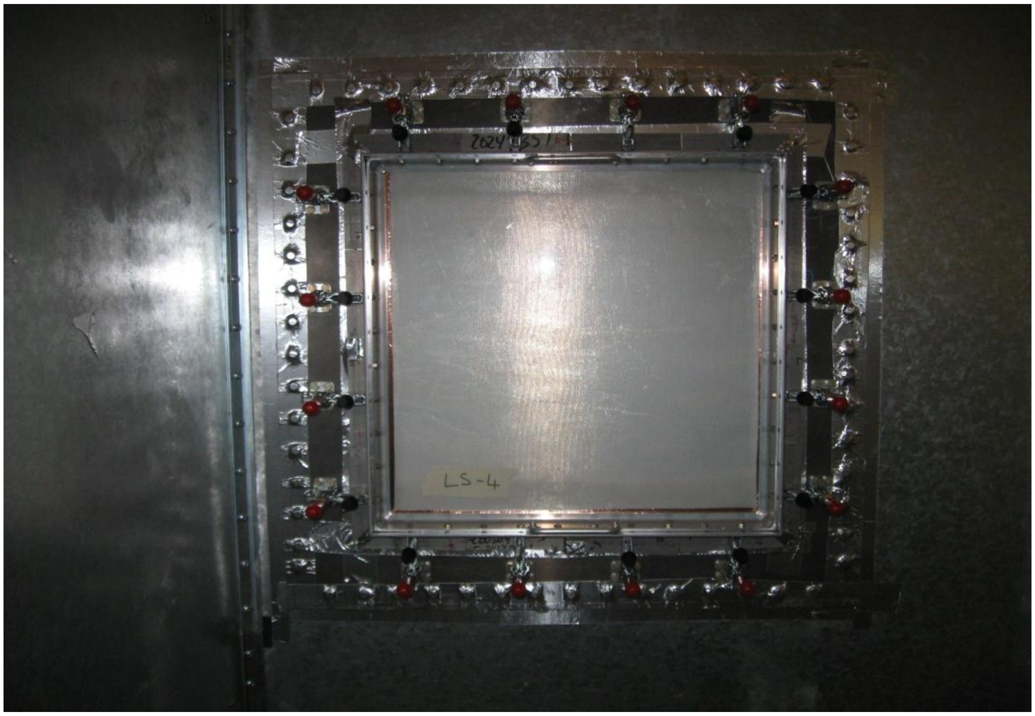


Figure E-14: Panel LS-4 mounted in chamber (with copper tape on top of core).

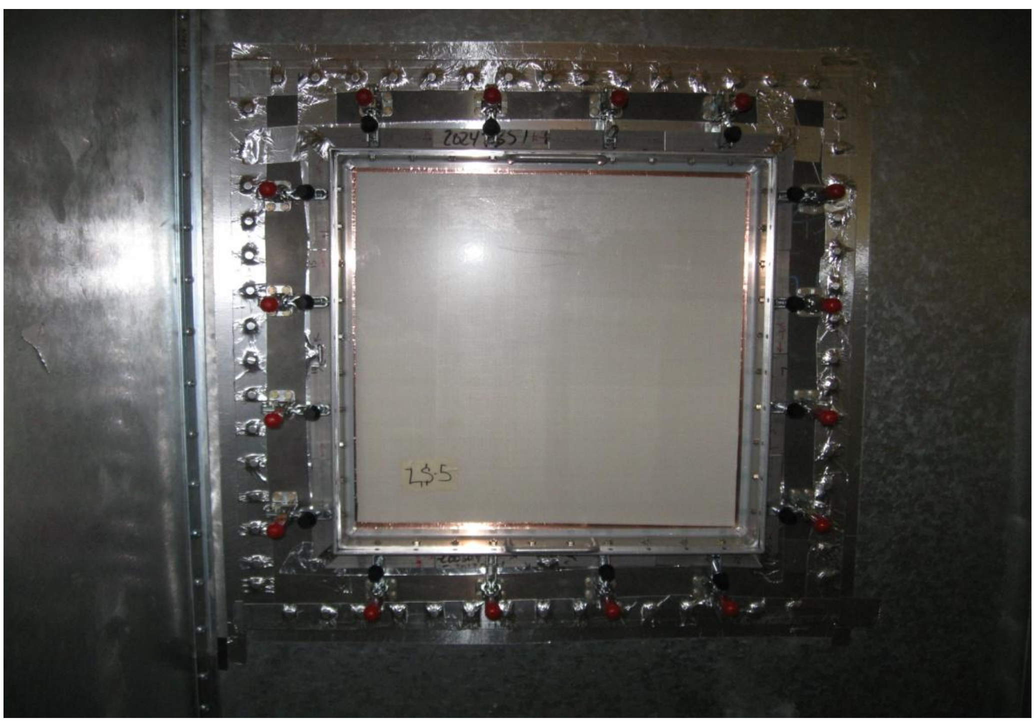


Figure E-15: Panel LS-5 mounted in chamber.

Figure E-16: Panel LS-6 mounted in chamber.

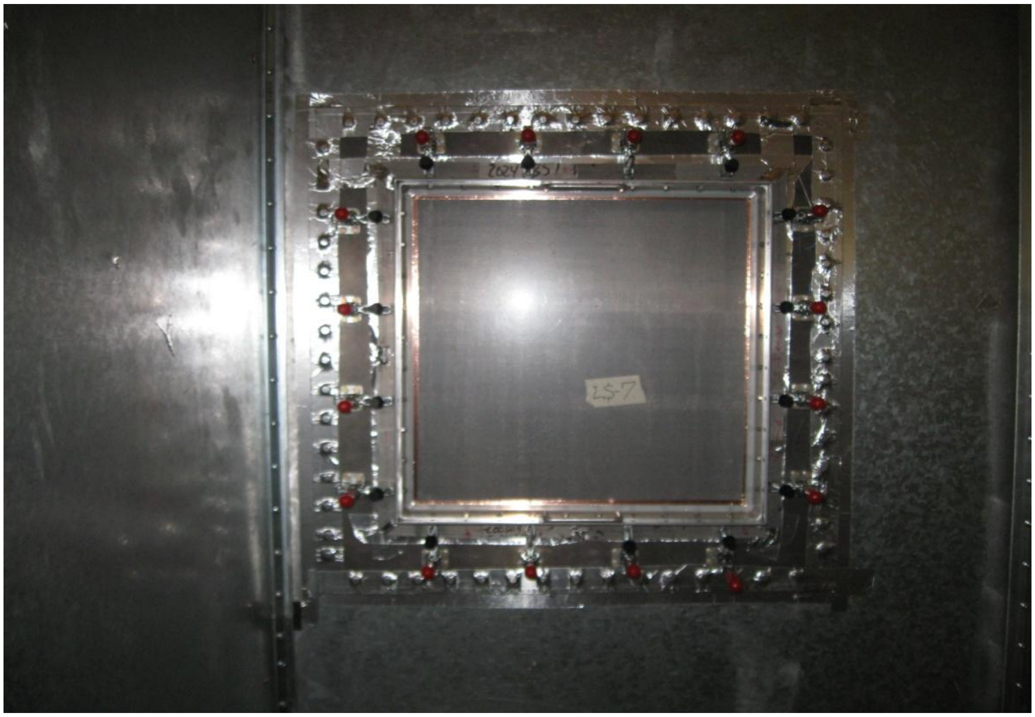


Figure E-17: Panel LS-7 mounted in chamber.

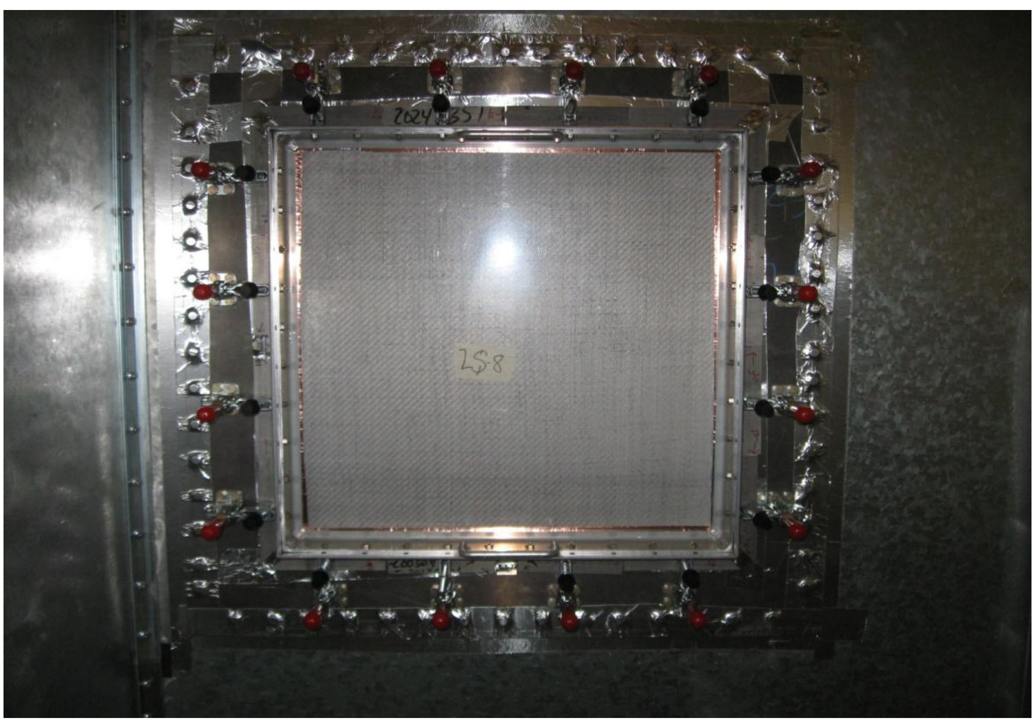


Figure E-18: Panel LS-8 mounted in chamber.

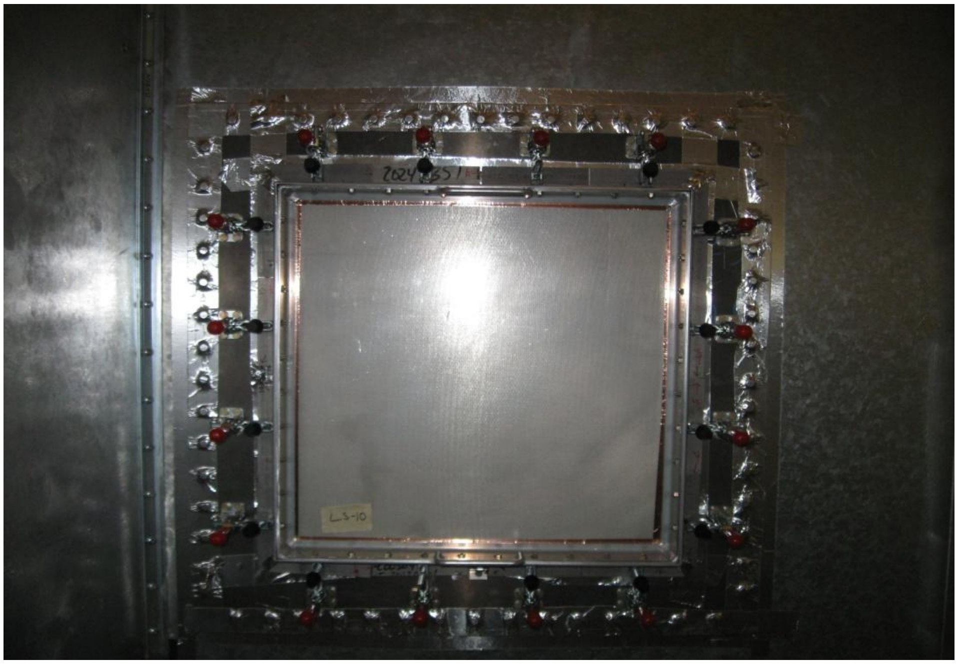


Figure E-19: Panel LS-9 mounted in chamber (mislabeled as10).

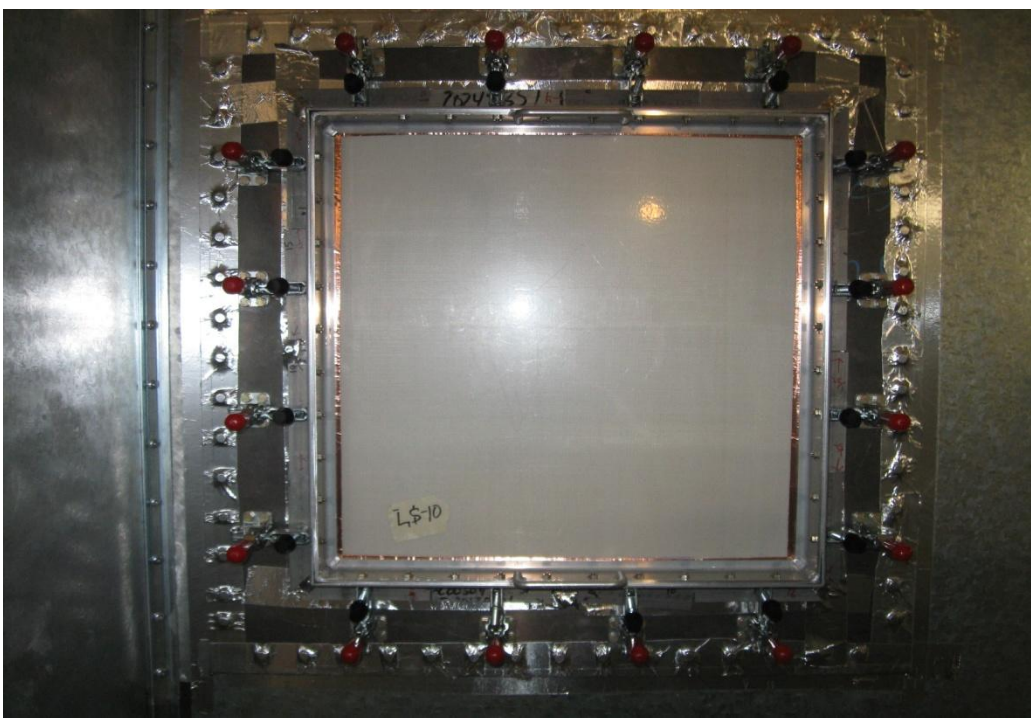


Figure E-20: Panel LS-10 mounted in chamber.

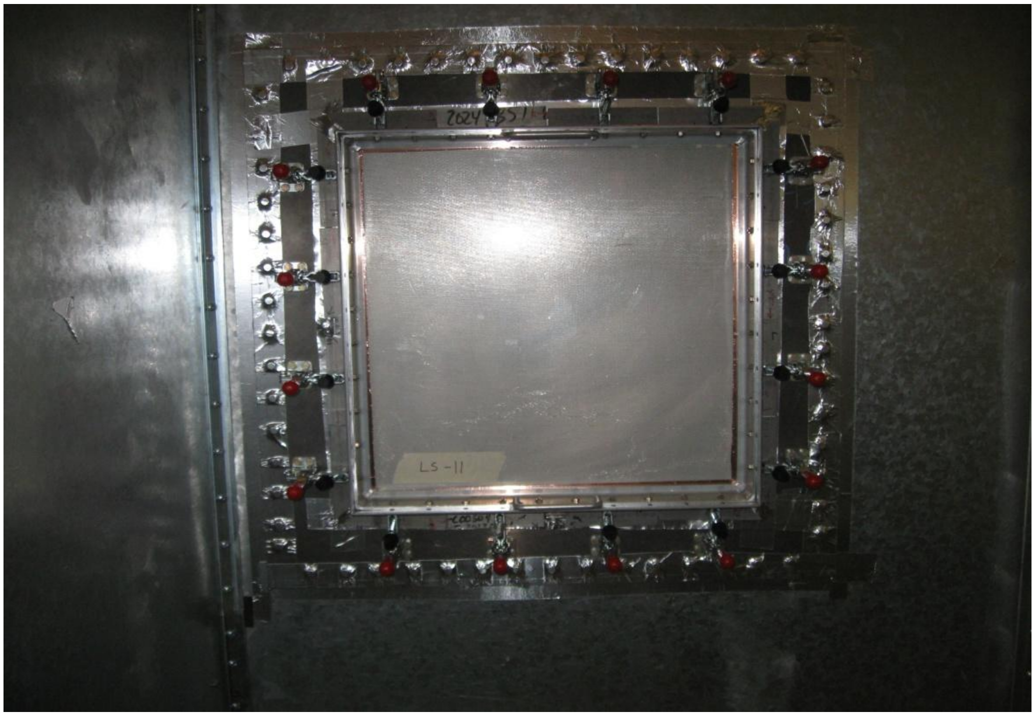


Figure E-21: Panel LS-11 mounted in chamber.

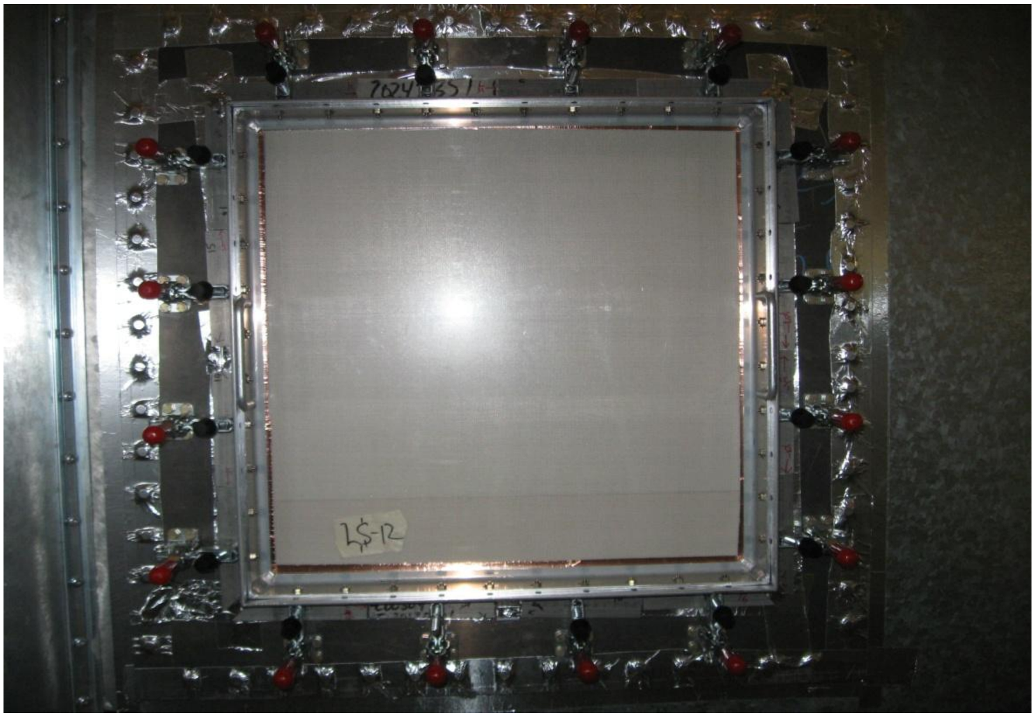


Figure E-22: Panel LS-12 mounted in chamber.

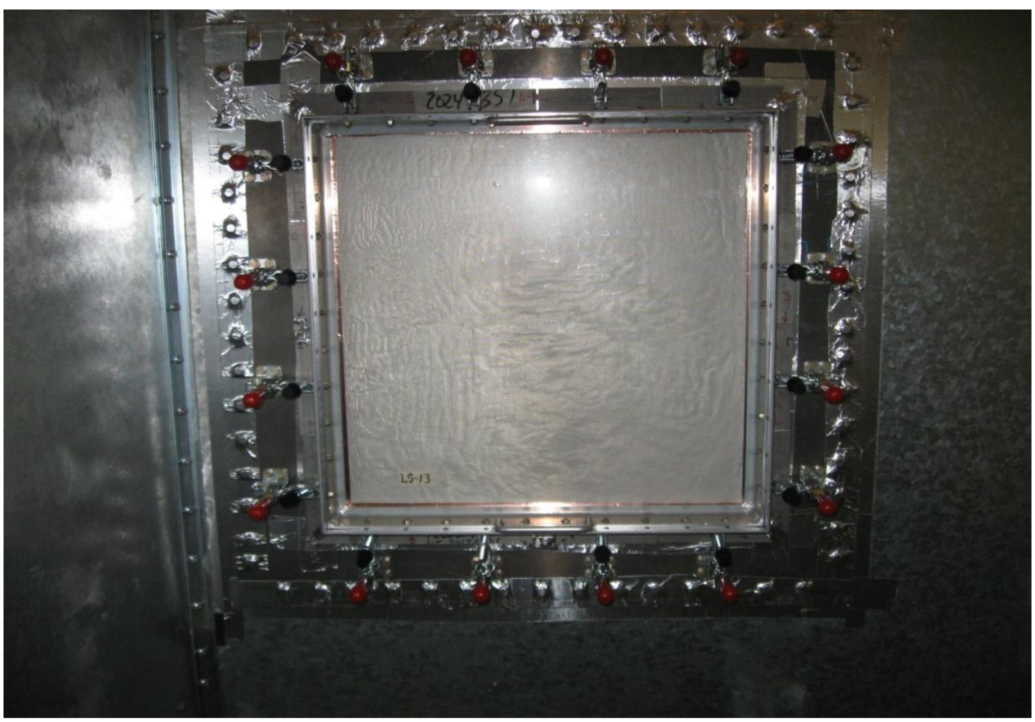


Figure E-23: Panel LS-13 mounted in chamber.

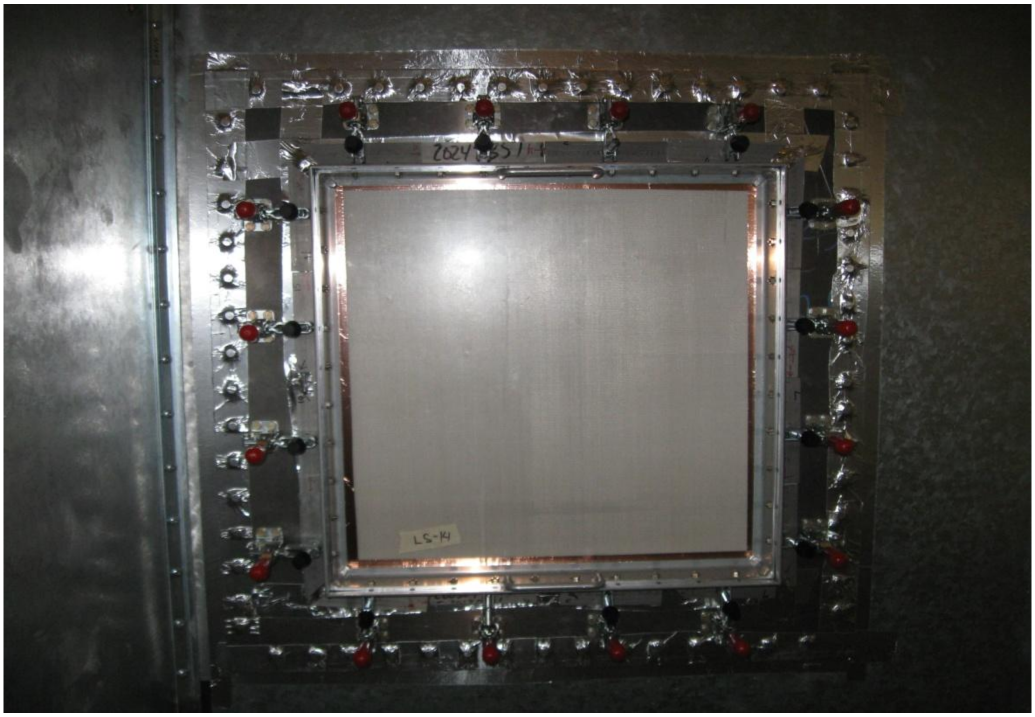


Figure E-24: Panel LS-14 mounted in chamber.

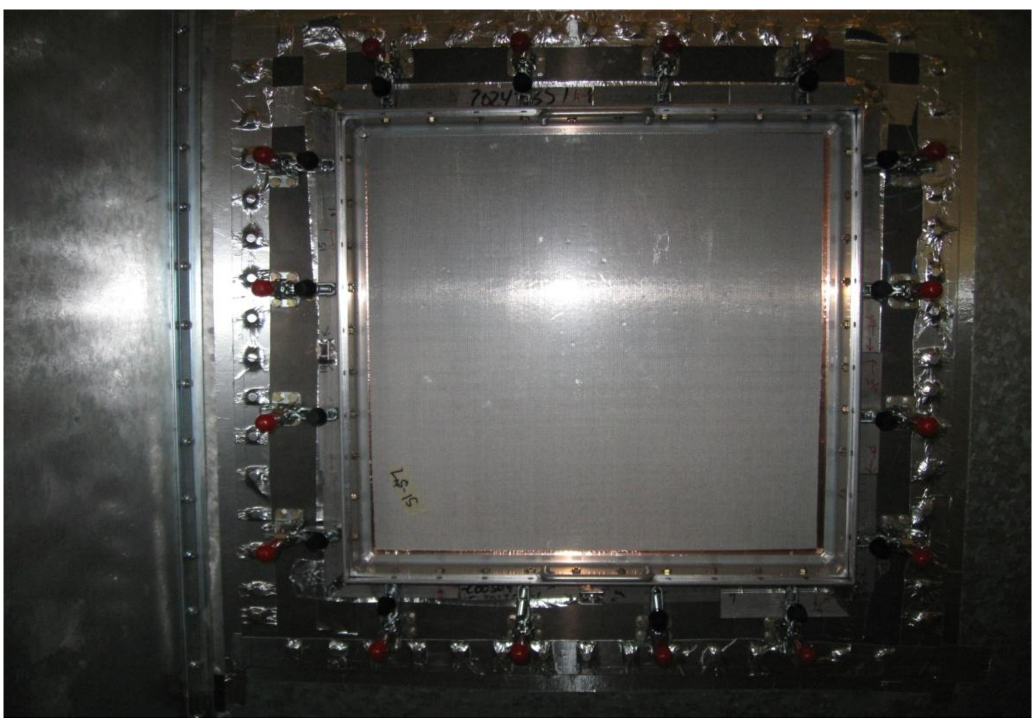


Figure E-25: Panel LS-15 mounted in chamber.

Figure E-26: Panel LS-18 showing flaw in LDS 50-01.

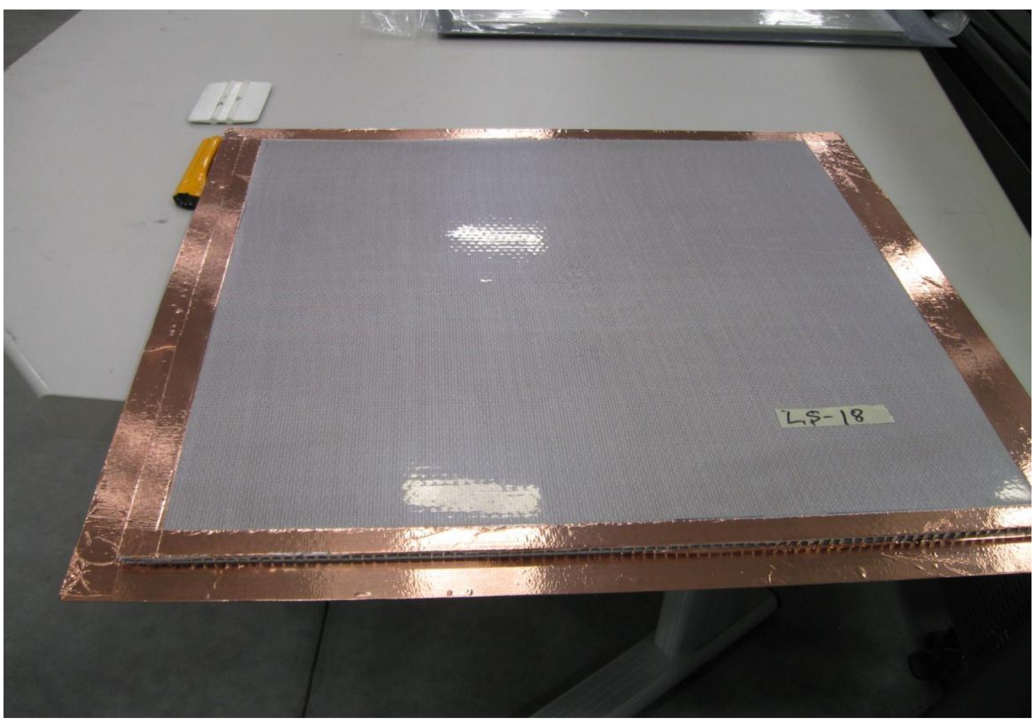


Figure E-27: Panel LS-18 with copper tape ready for chamber.

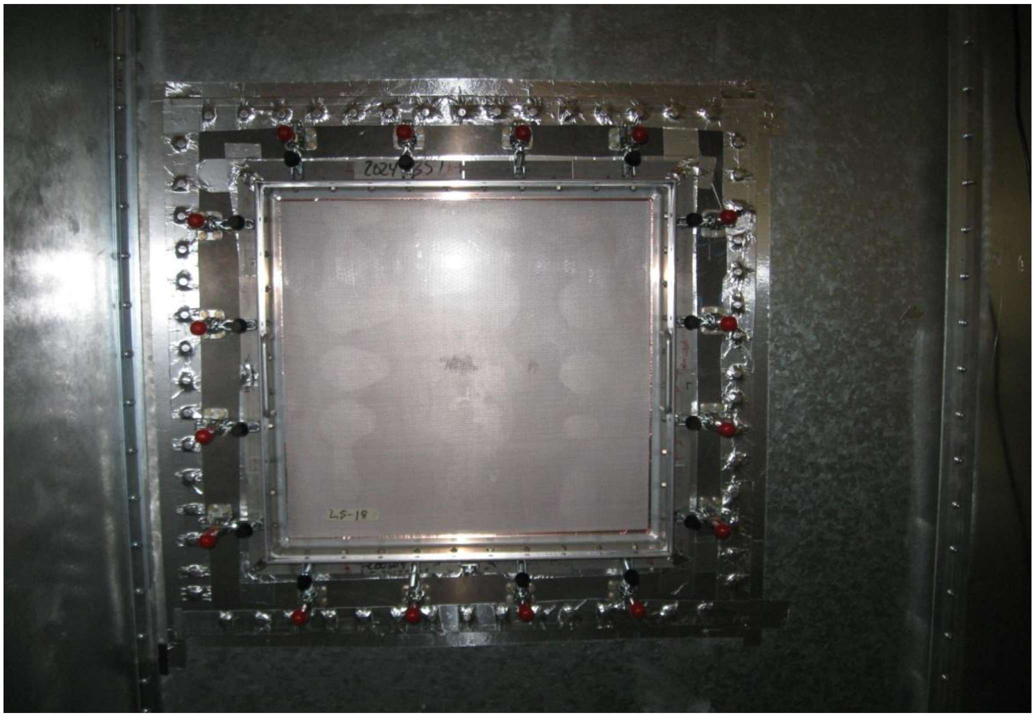


Figure E-28: Panel LS-18 mounted in chamber.

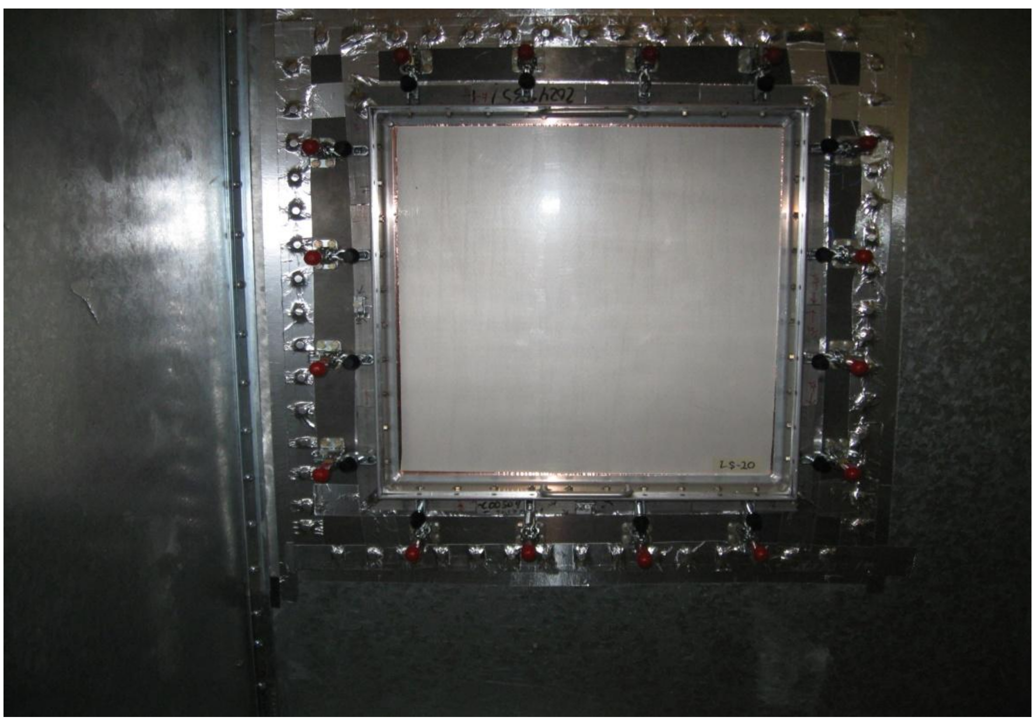


Figure E-29: Panel LS-20 mounted in chamber.

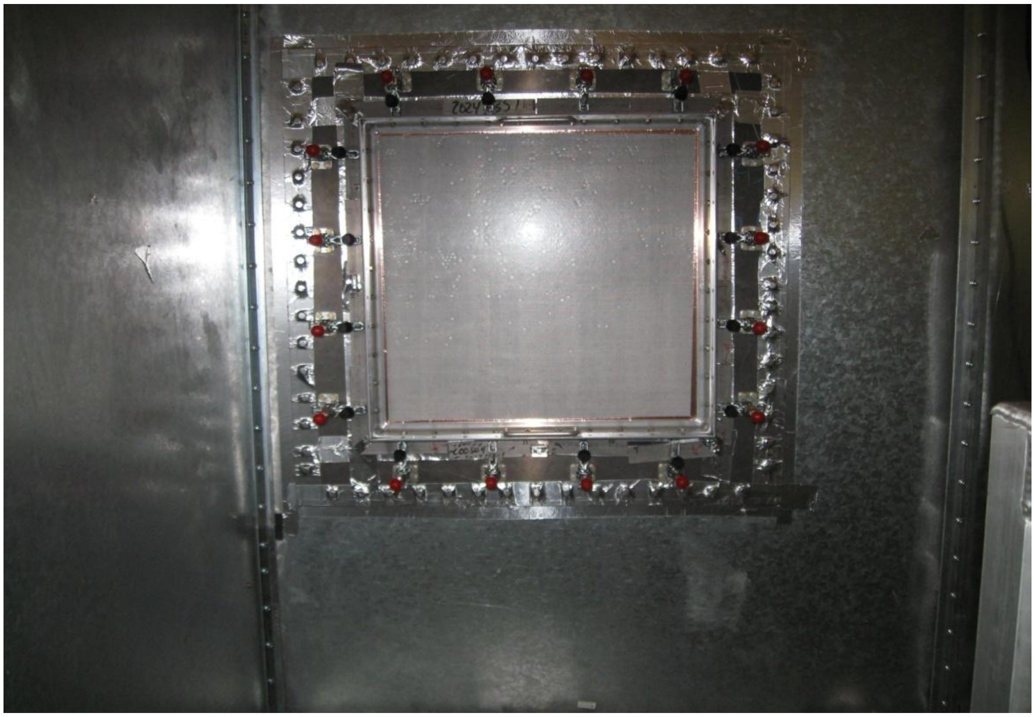


Figure E-30: Panel LS-21 mounted in chamber.

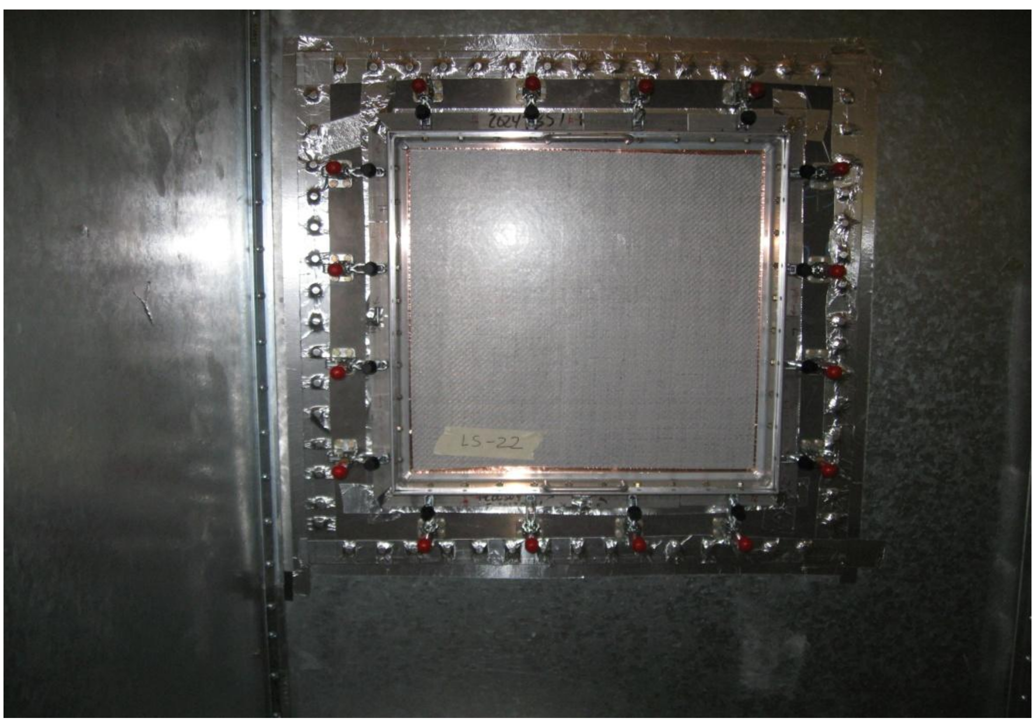


Figure E-31: Panel LS-22 mounted in chamber.

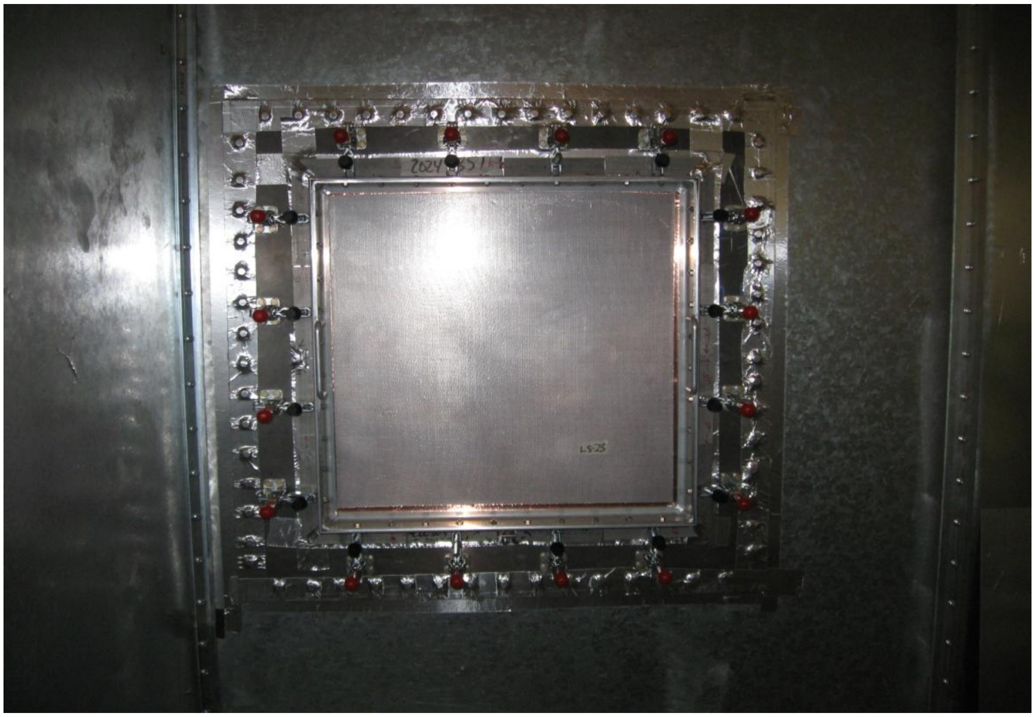


Figure E-32: Panel LS-23 mounted in chamber.

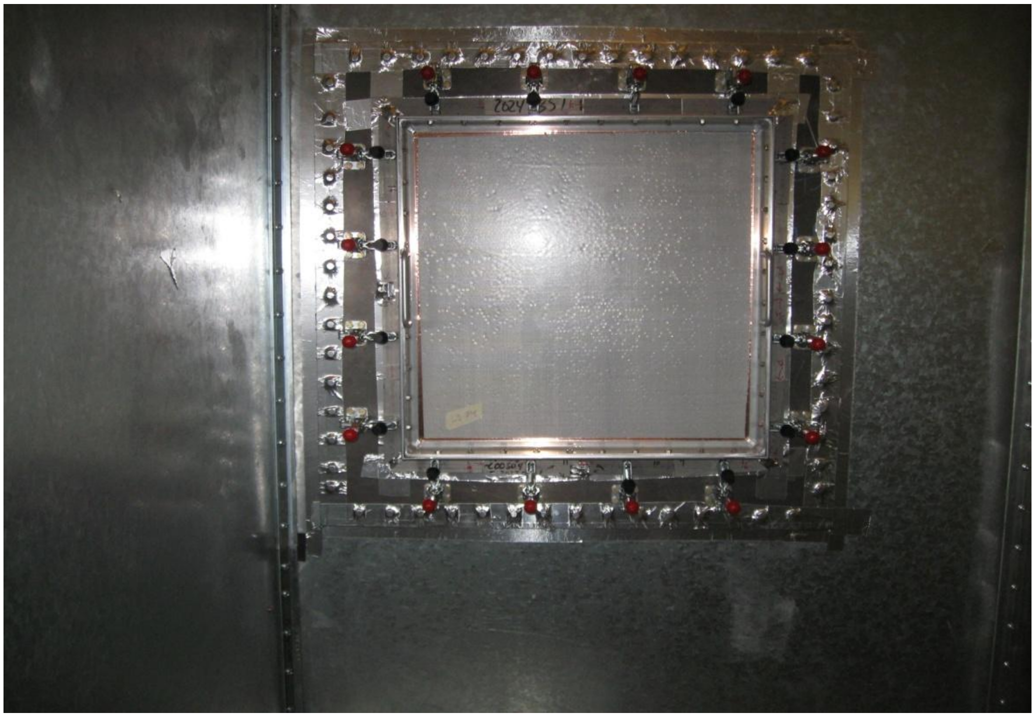


Figure E-33: Panel LS-24 mounted in chamber.

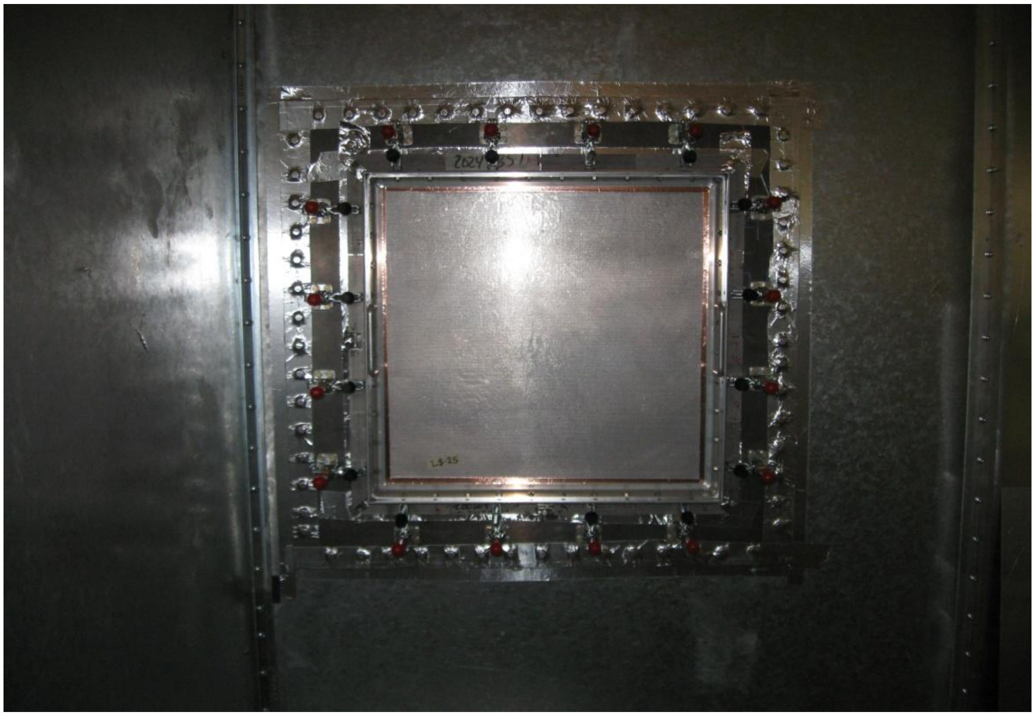


Figure E-34: Panel LS-25 mounted in chamber.

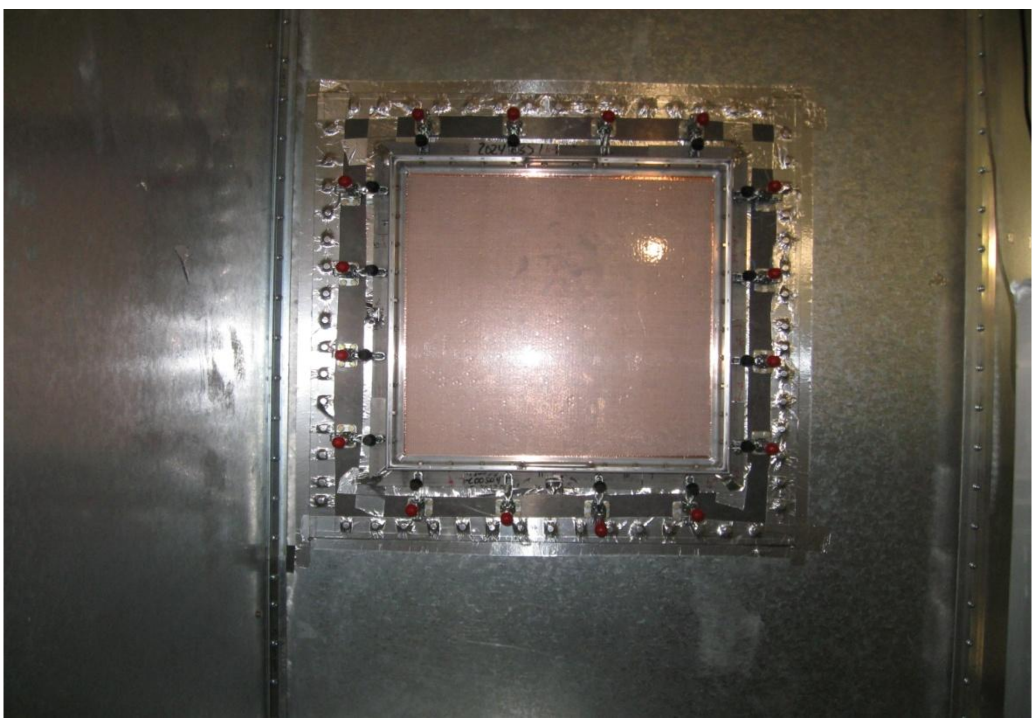


Figure E-35: Panel LS-26 mounted in chamber.

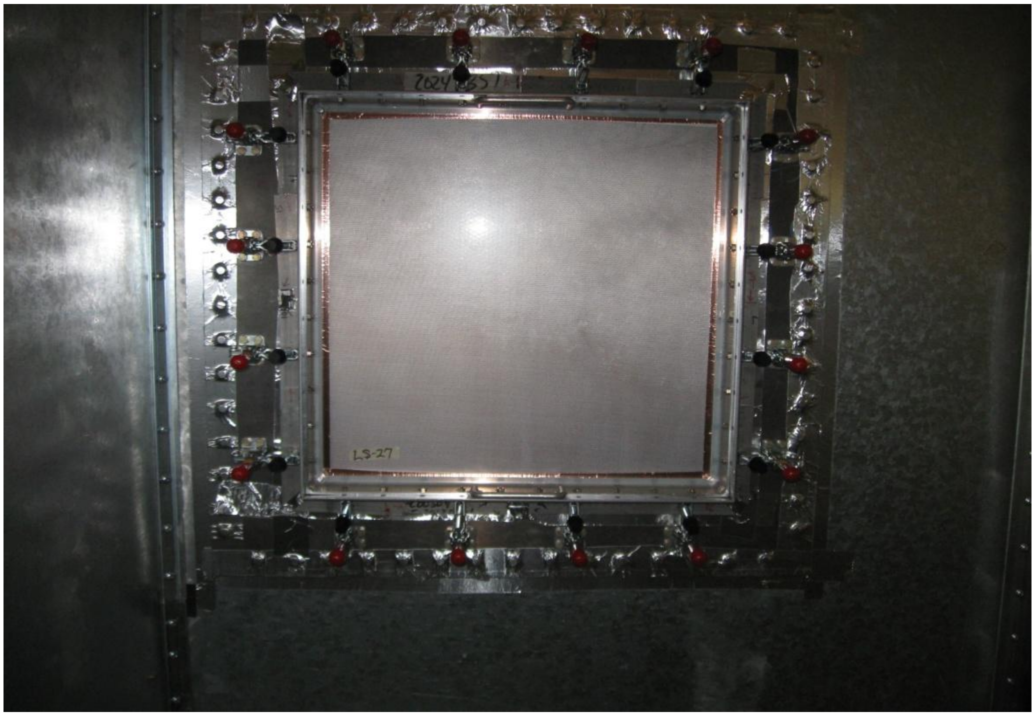


Figure E-36: Panel LS-27 mounted in chamber.

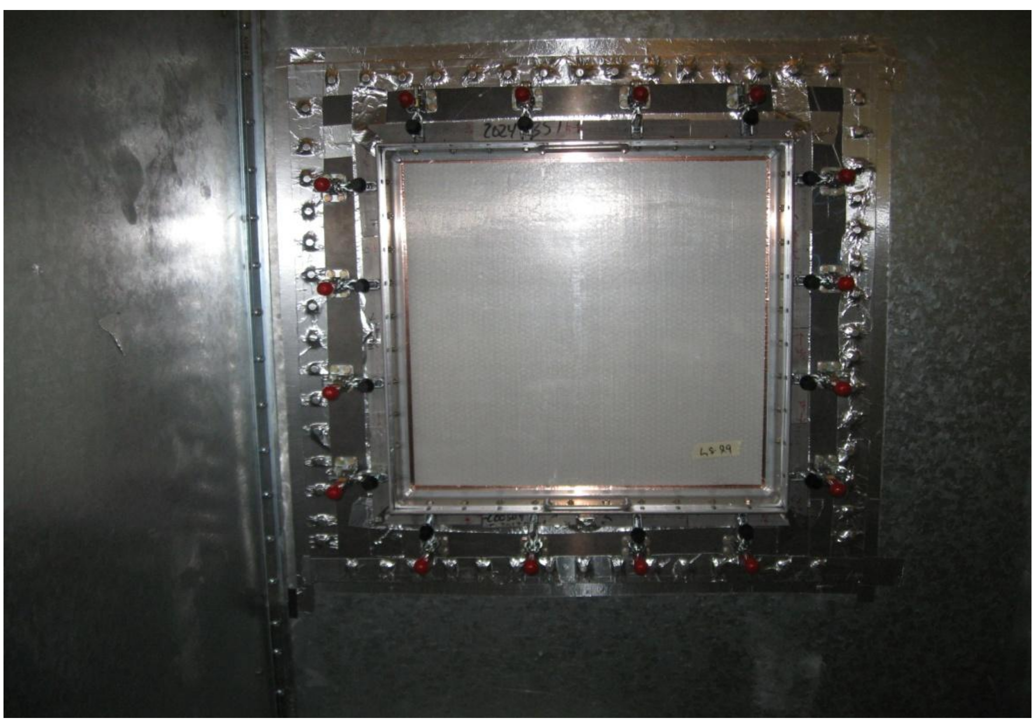


Figure E-37: Panel LS-29 mounted in chamber.

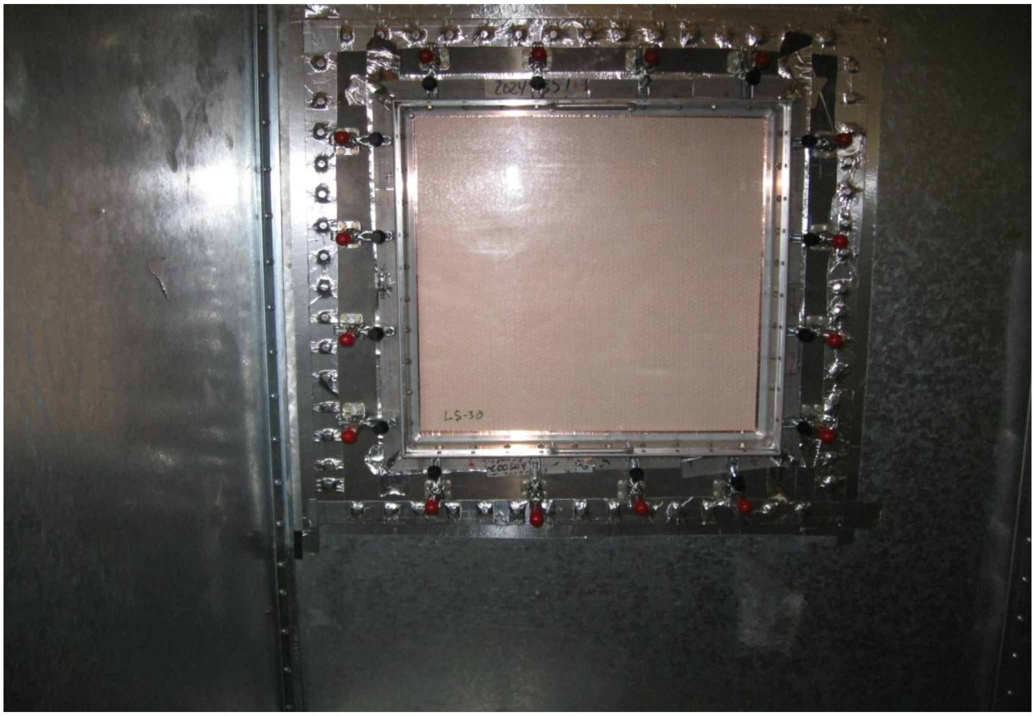


Figure E-38: Panel LS-30 mounted in chamber.

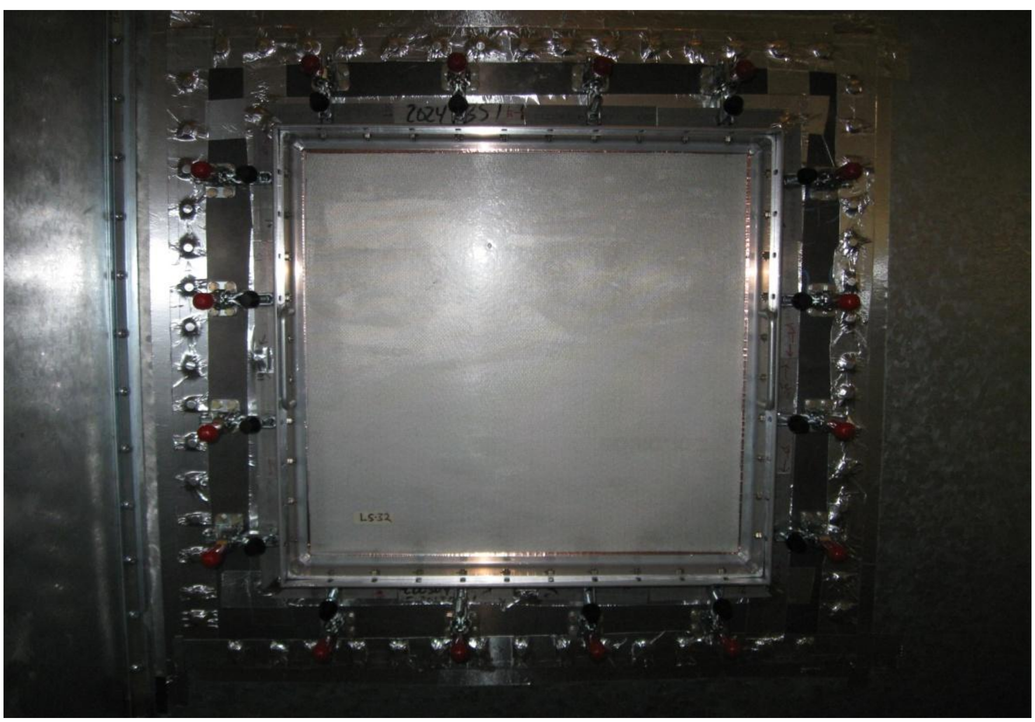


Figure E-39: Panel LS-32 mounted in chamber.

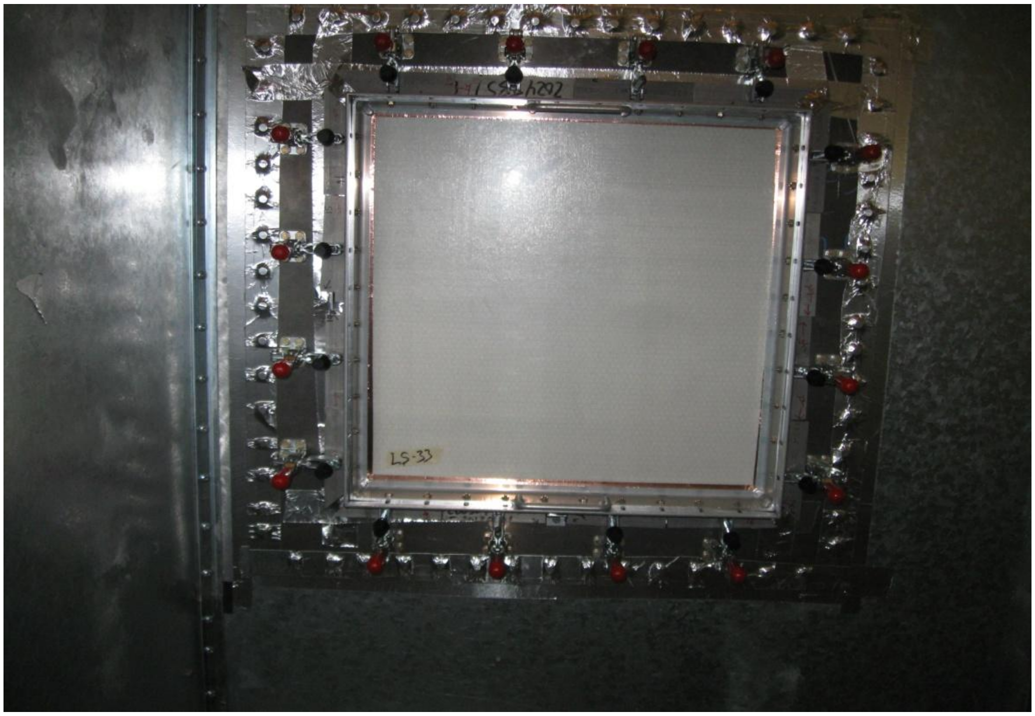


Figure E-40: Panel LS-33 mounted in chamber.

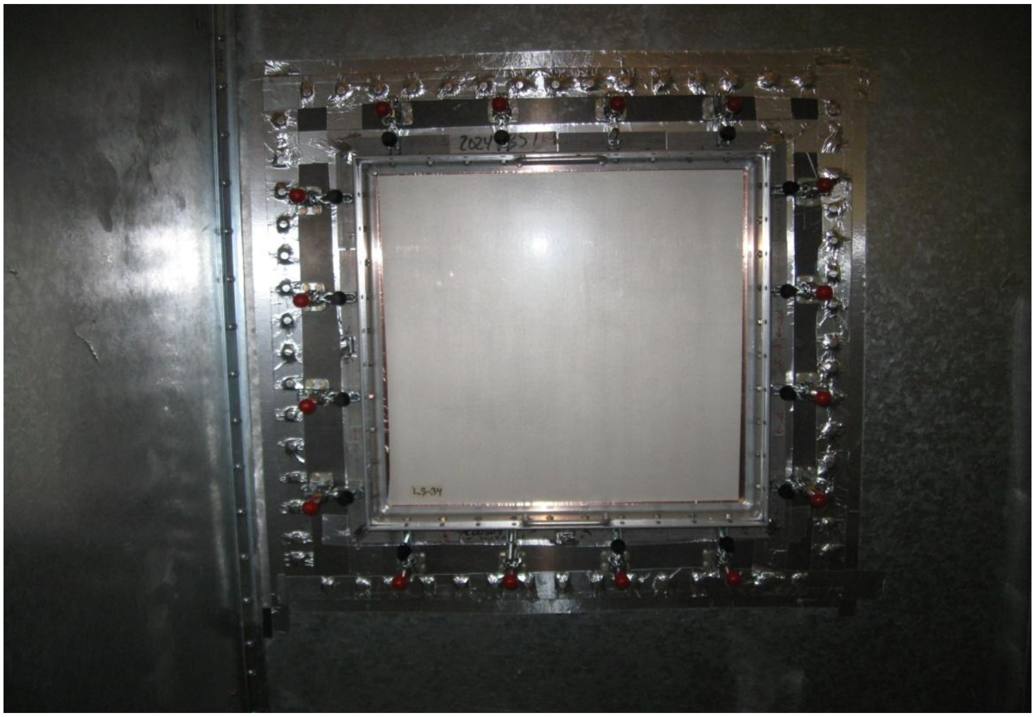


Figure E-41: Panel LS-34 mounted in chamber.

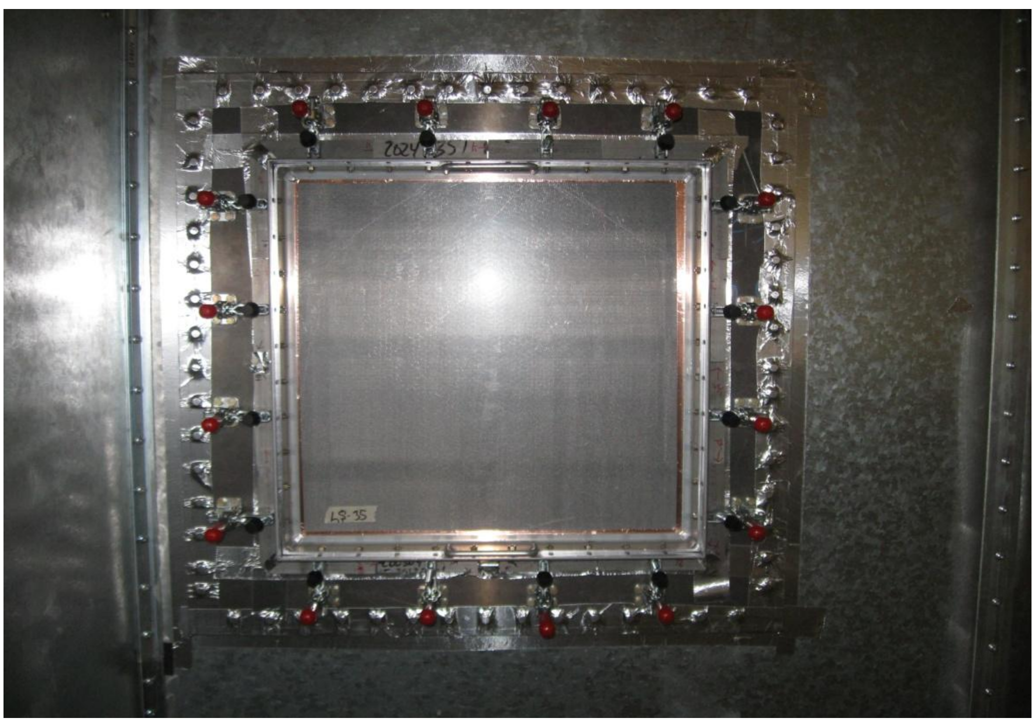


Figure E-42: Panel LS-35 mounted in chamber.

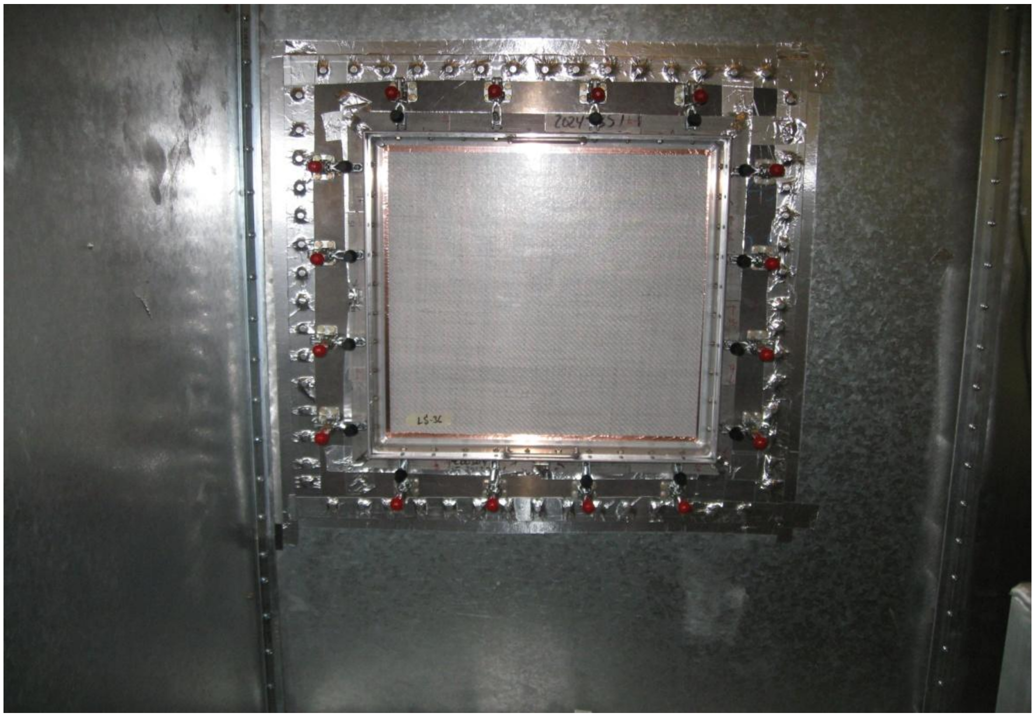


Figure E-43: Panel LS-36 mounted in chamber.

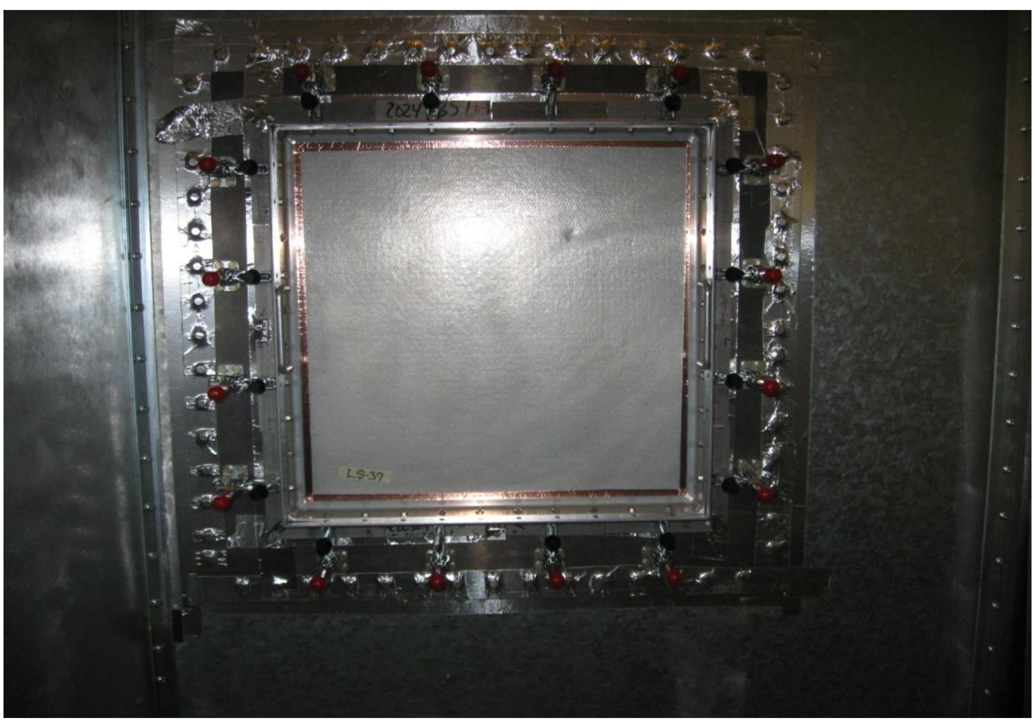


Figure E-44: Panel LS-37 mounted in chamber.

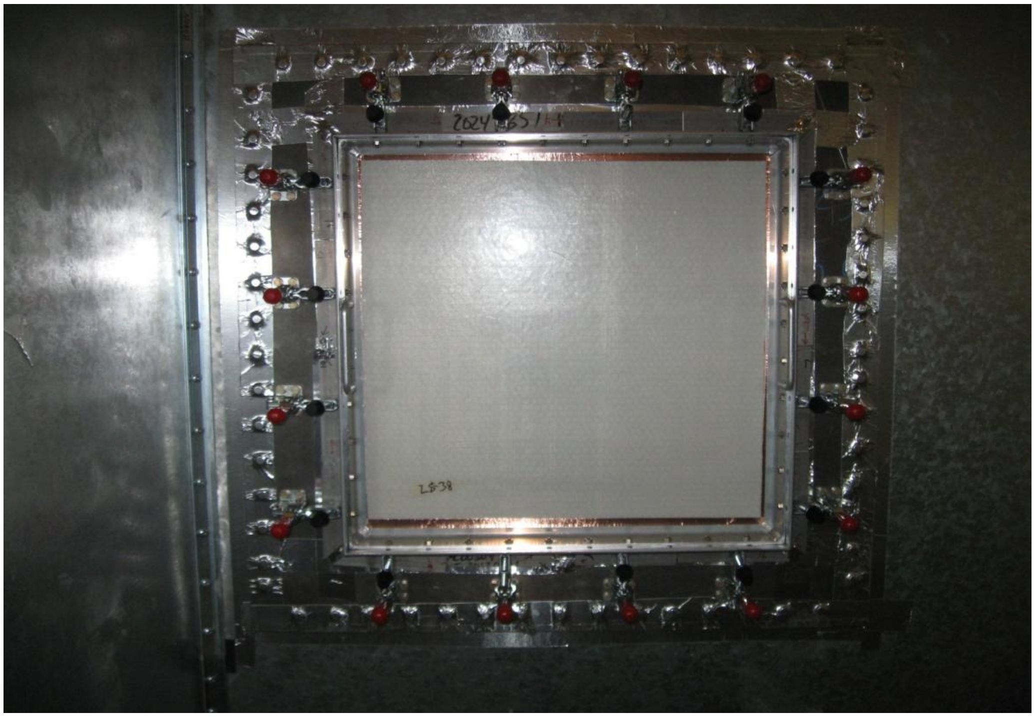


Figure E-45: Panel LS-38 mounted in chamber.

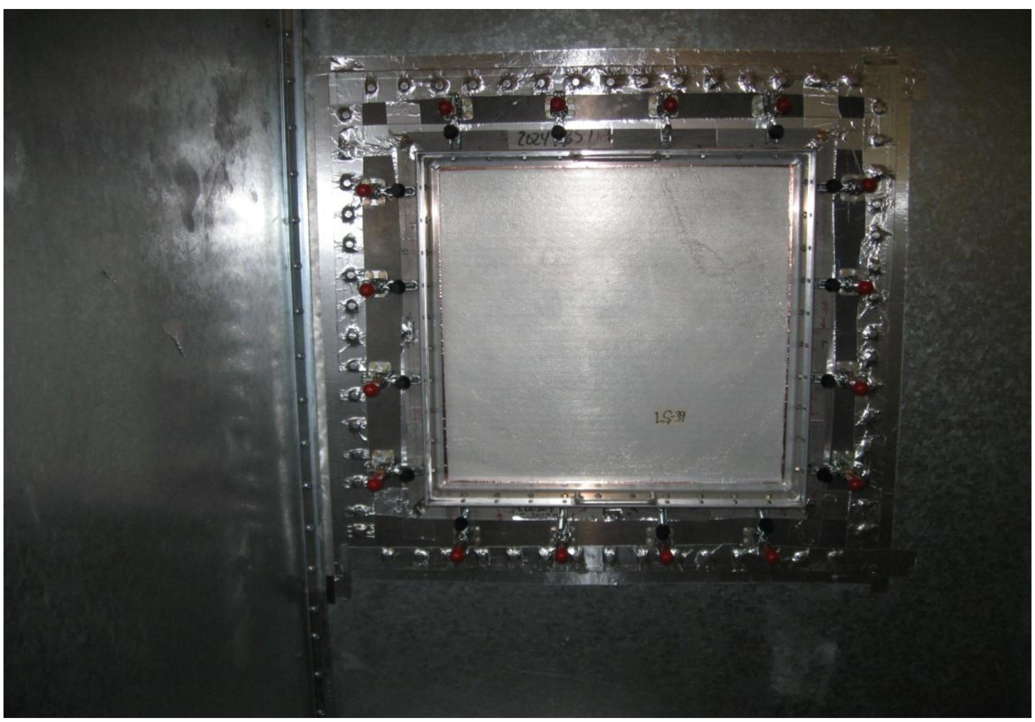


Figure E-46: Panel LS-39 mounted in chamber.

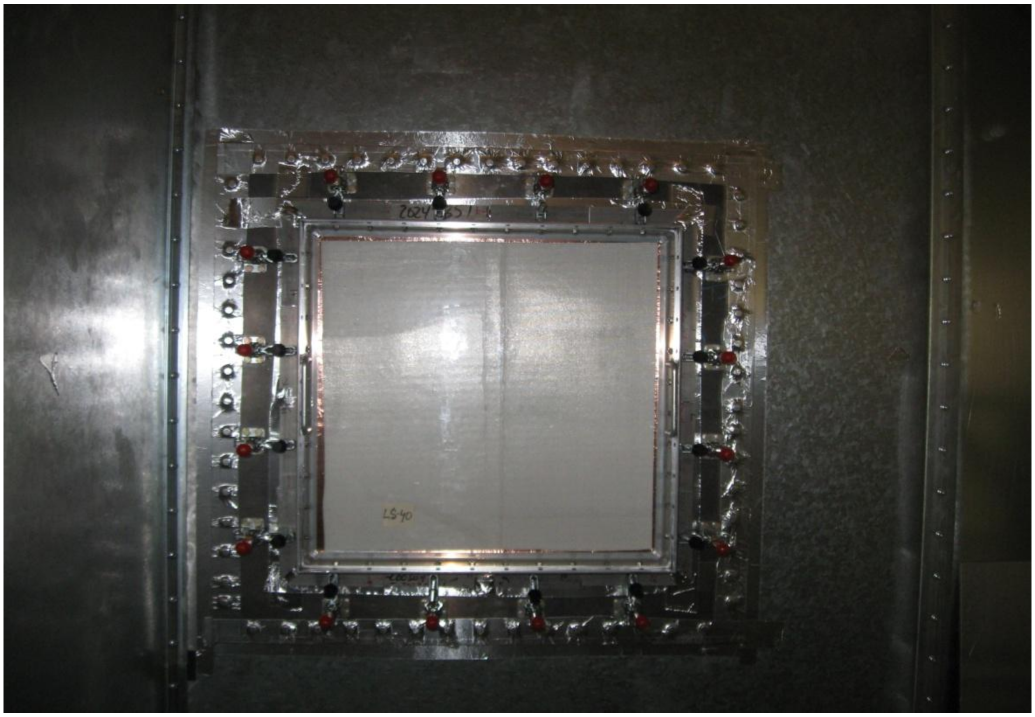


Figure E-47: Panel LS-40 mounted in chamber.

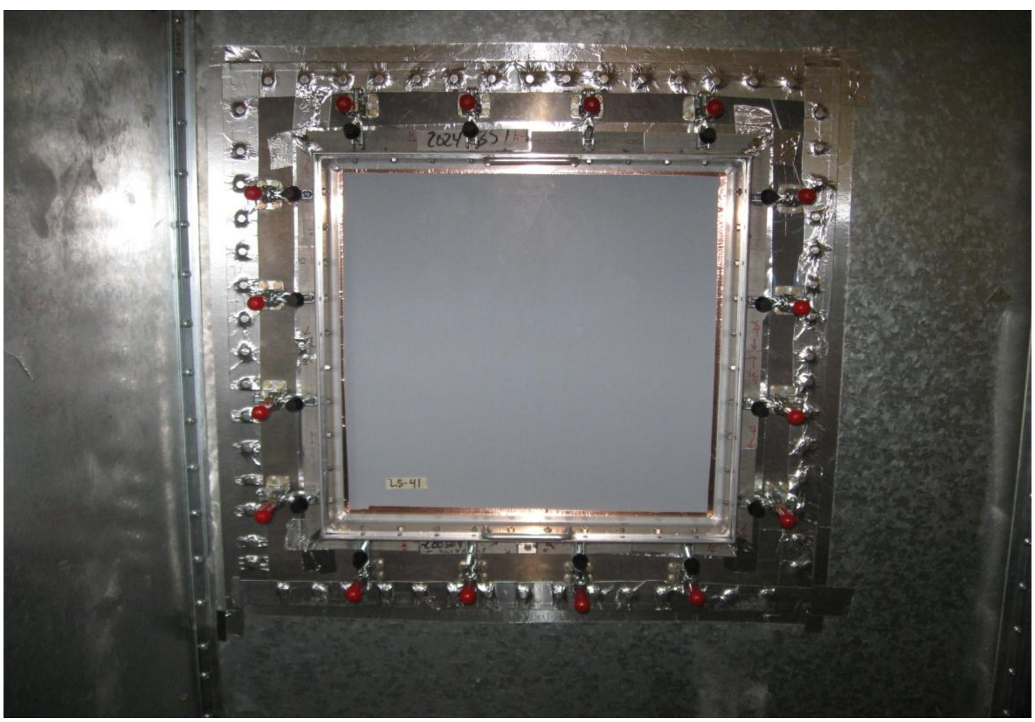


Figure E-48: Panel LS-41 mounted in chamber.

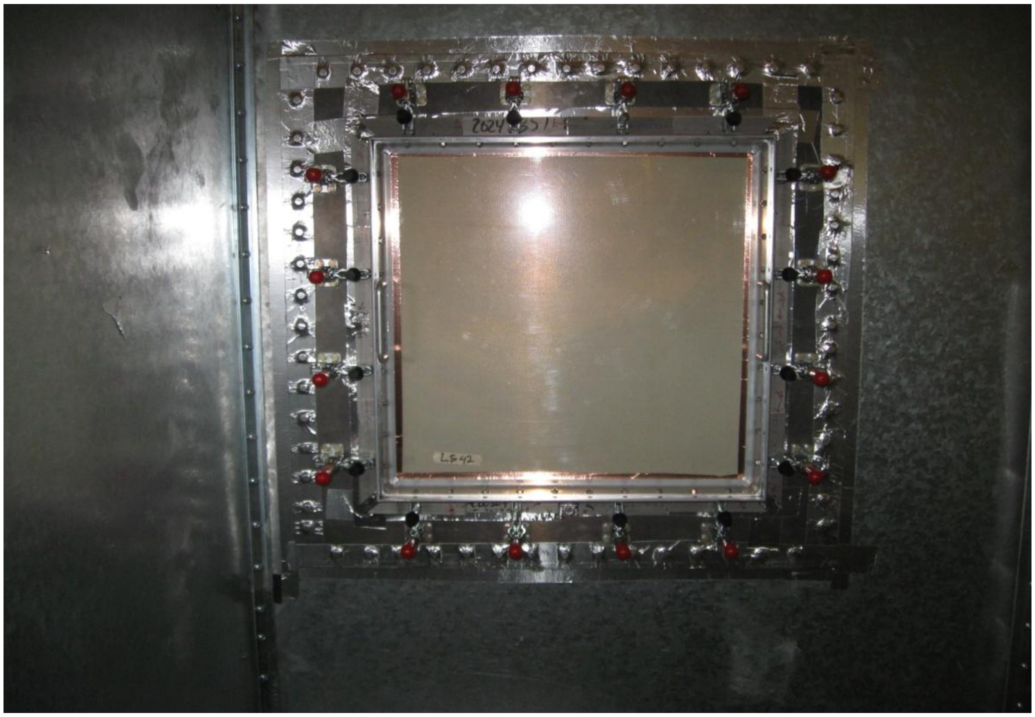


Figure E-49: Panel LS-42 mounted in chamber.

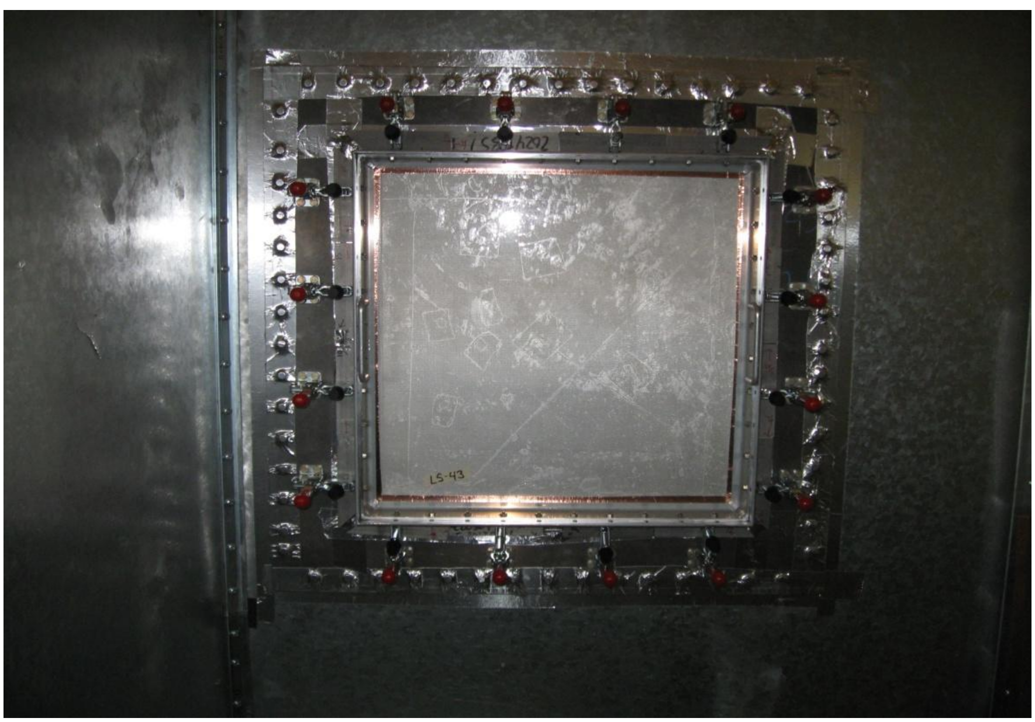


Figure E-50: Panel LS-43 mounted in chamber.

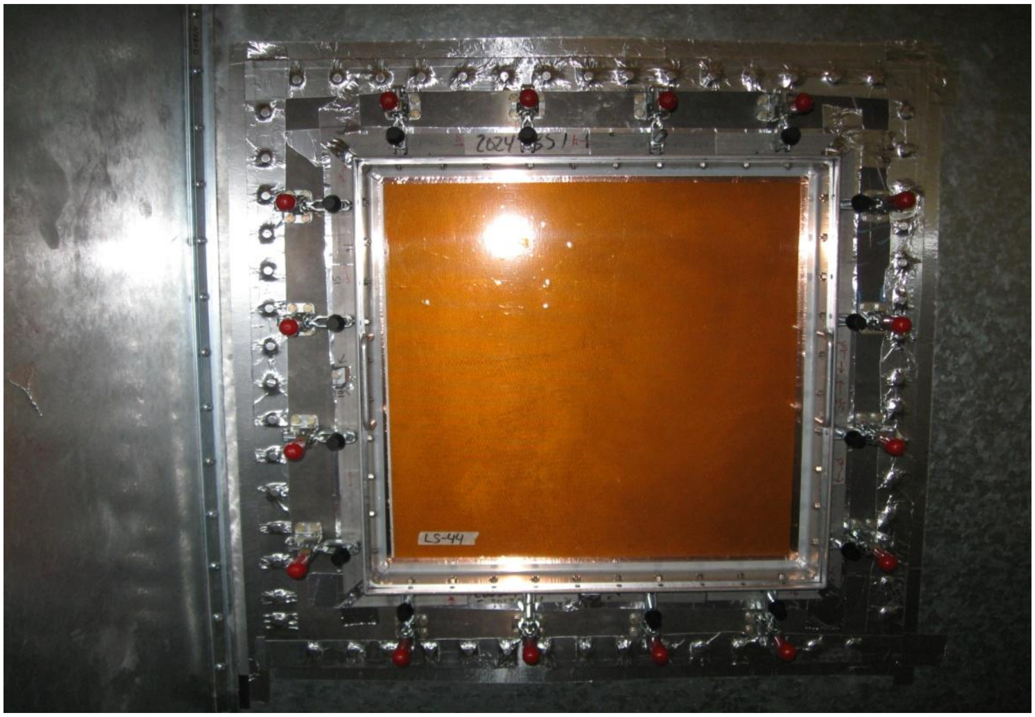


Figure E-51: Panel LS-44 mounted in chamber.

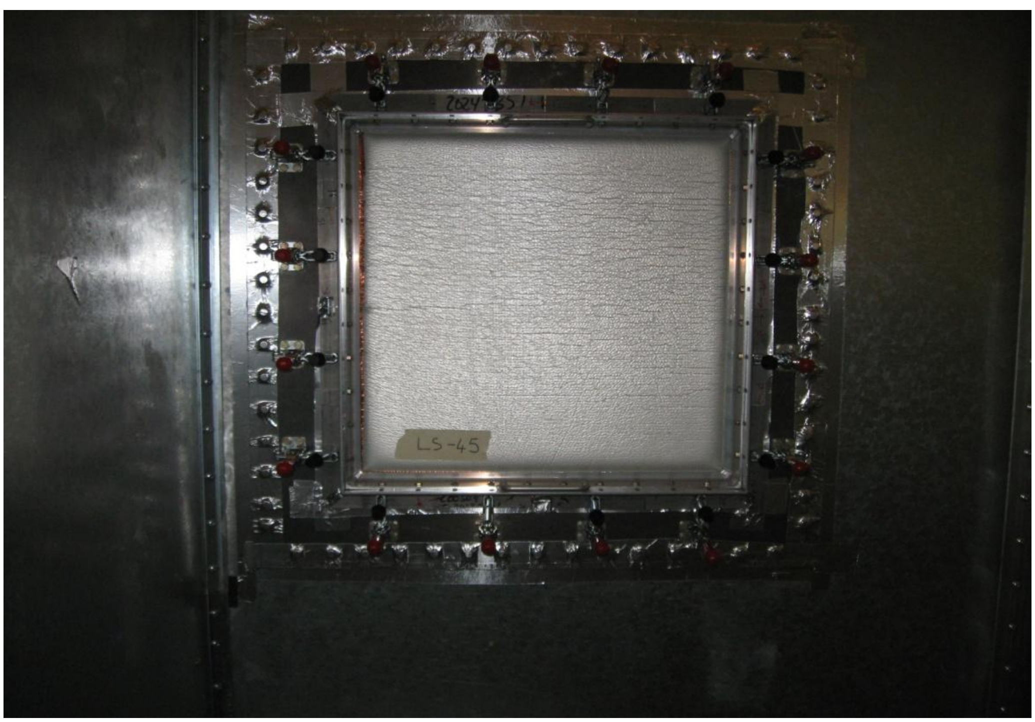


Figure E-52: Panel LS-45 mounted in chamber.

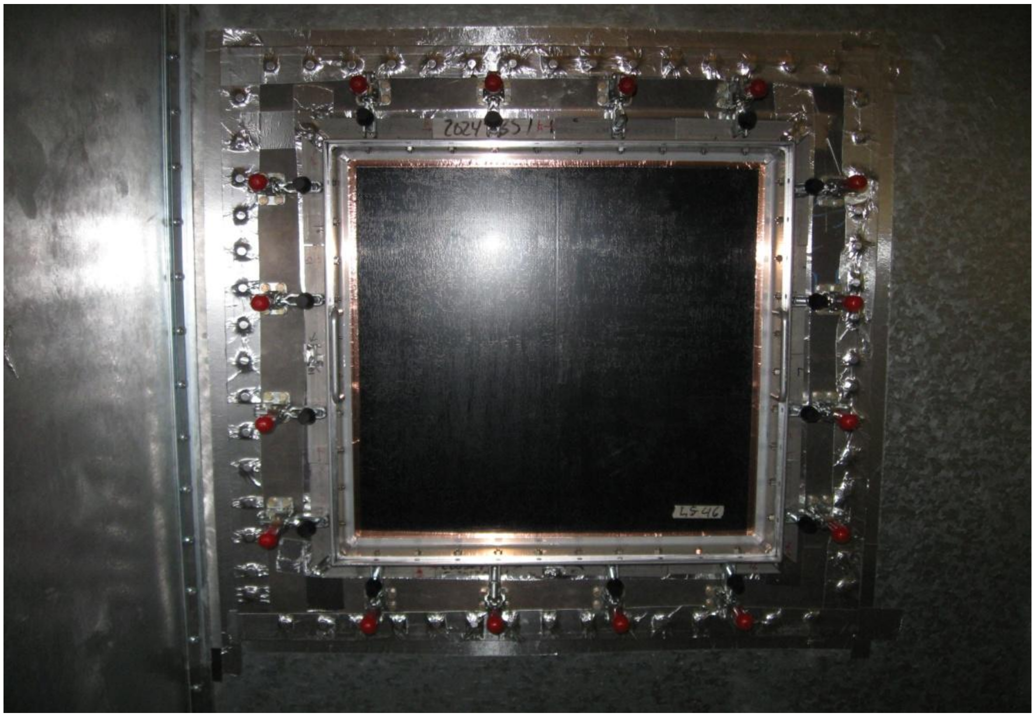


Figure E-53: Panel LS-46 mounted in chamber.

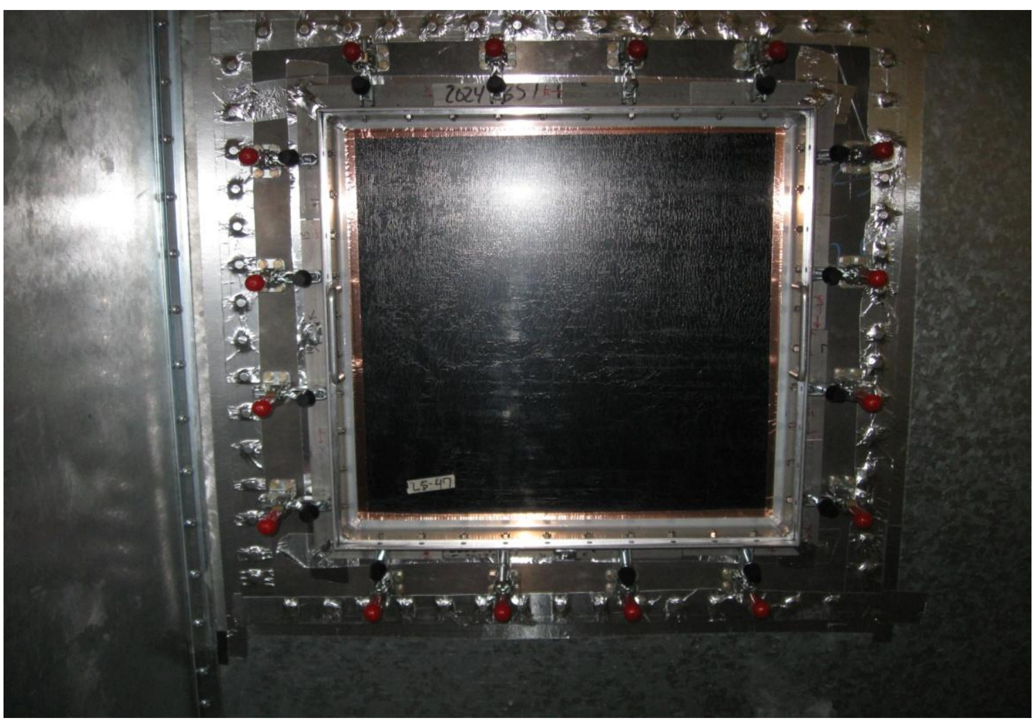


Figure E-54: Panel LS-47 mounted in chamber.

Appendix F
First-Generation Shielding Effectiveness Test Data

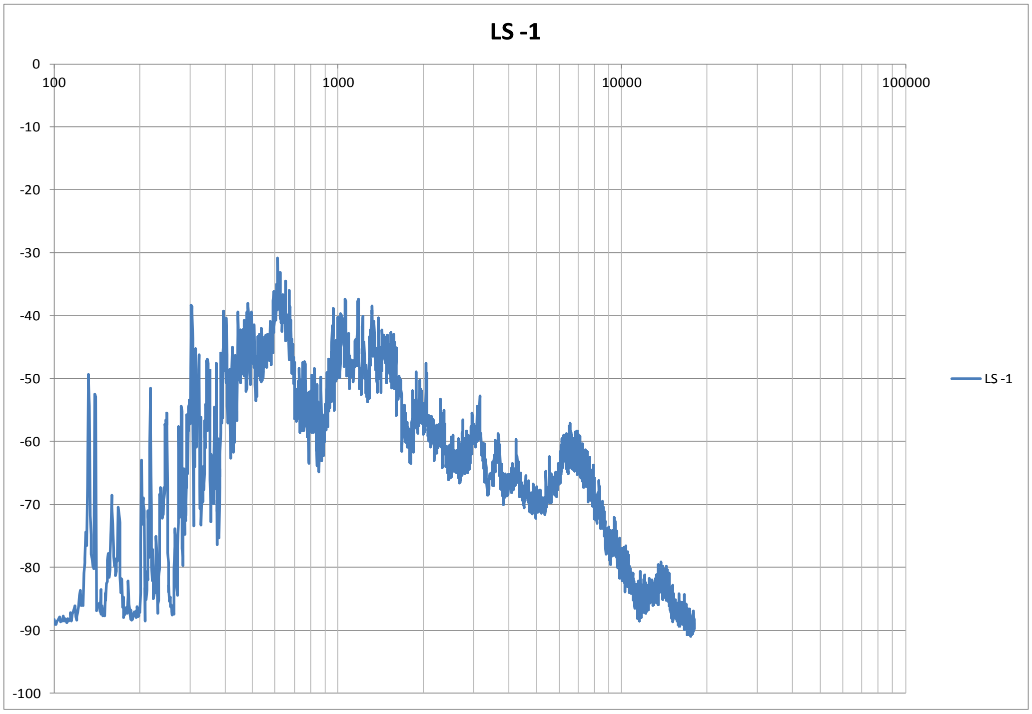


Figure F-1: Panel LS-1shielding effectiveness data plot.

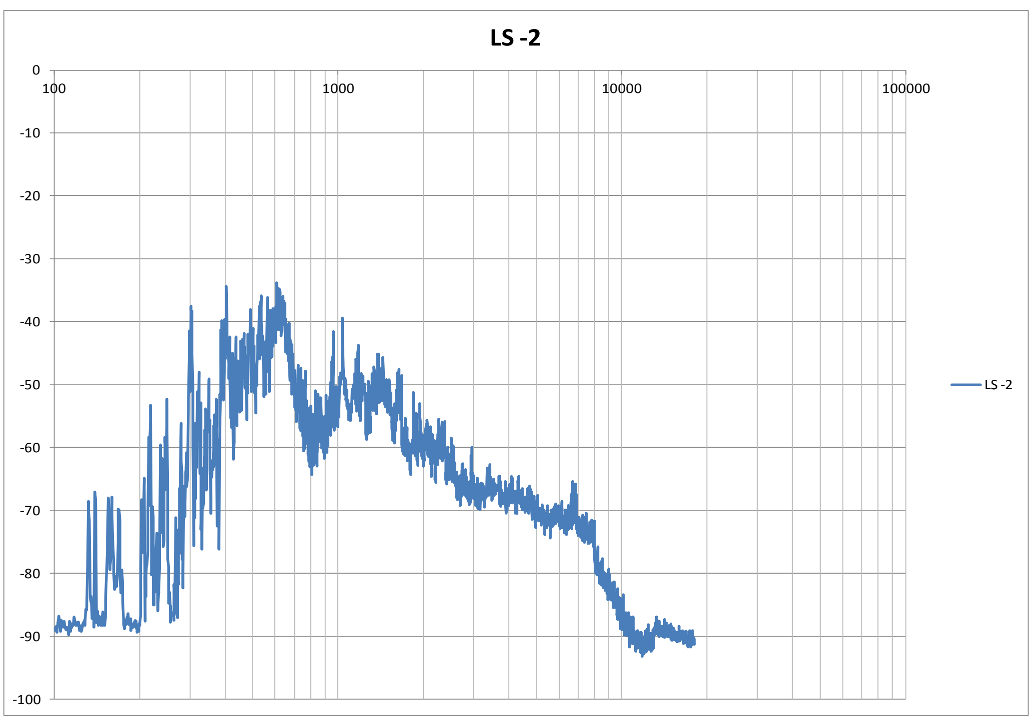


Figure F-2: Panel LS-2 shielding effectiveness data plot.

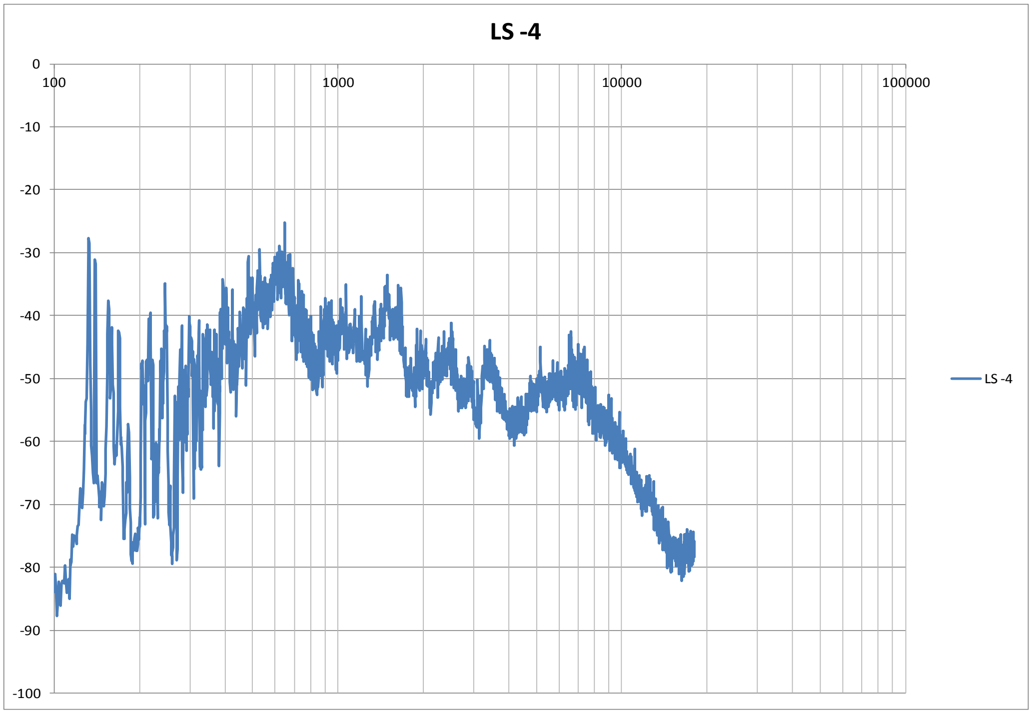


Figure F-3: Panel LS-4 shielding effectiveness data plot.

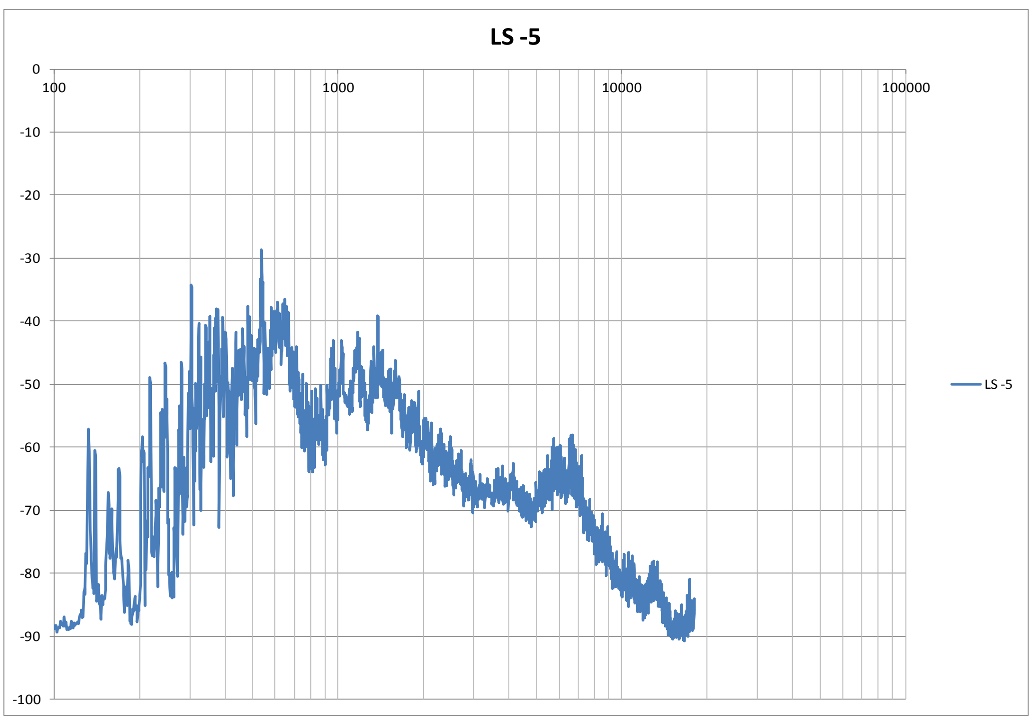


Figure F-4: Panel LS-5 shielding effectiveness data plot.

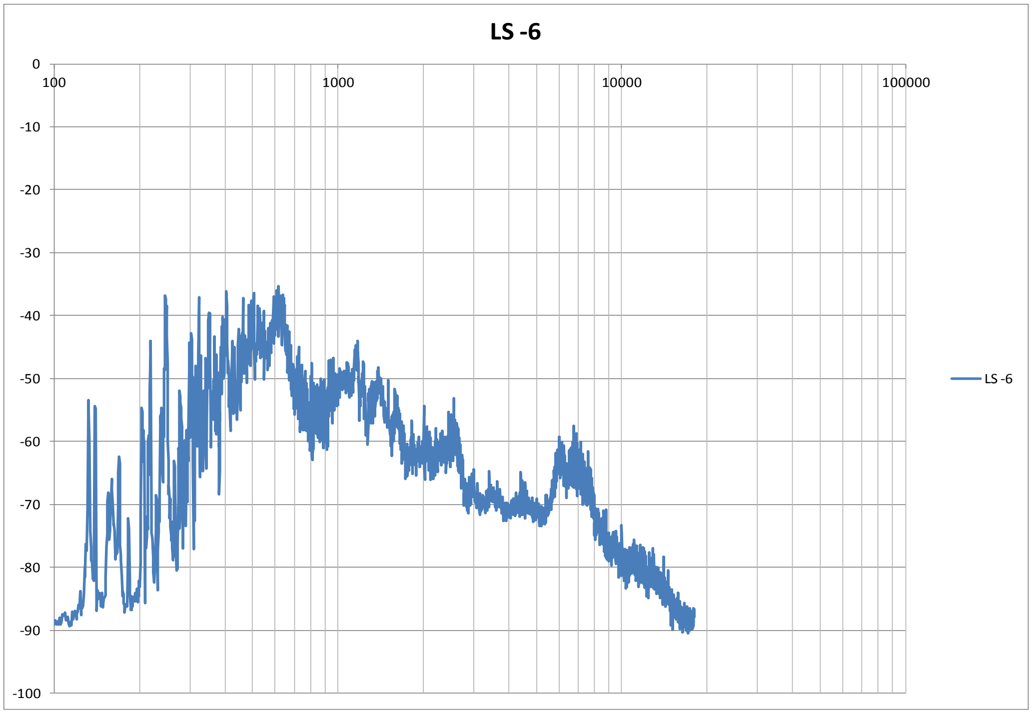


Figure F-5: Panel LS-6 shielding effectiveness data plot.

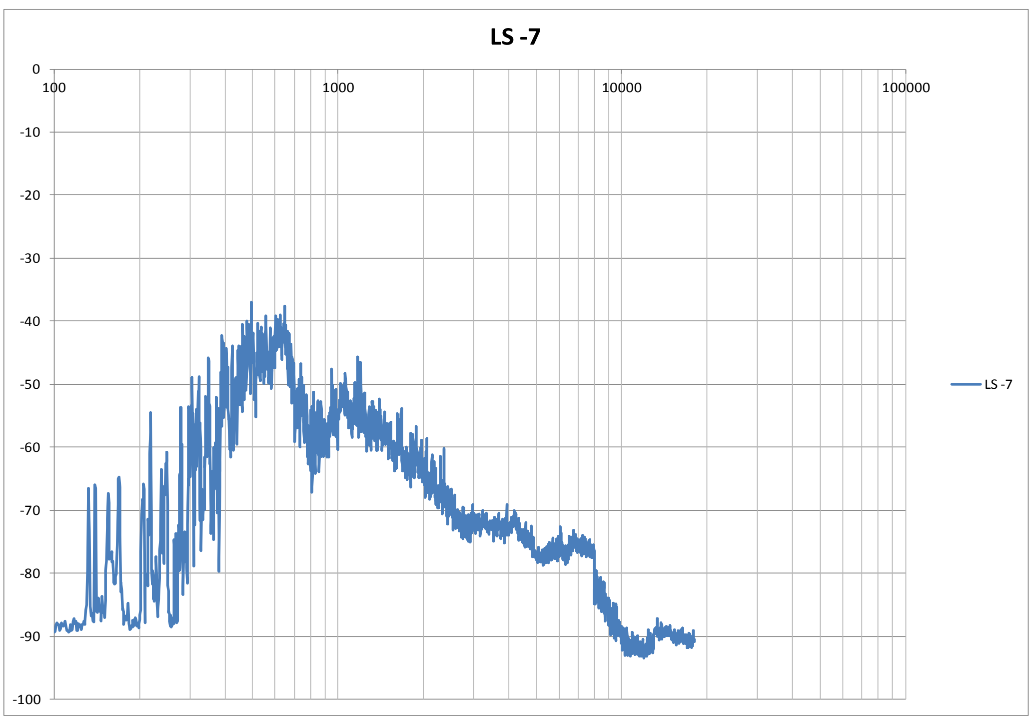


Figure F-6: Panel LS-7 shielding effectiveness data plot.

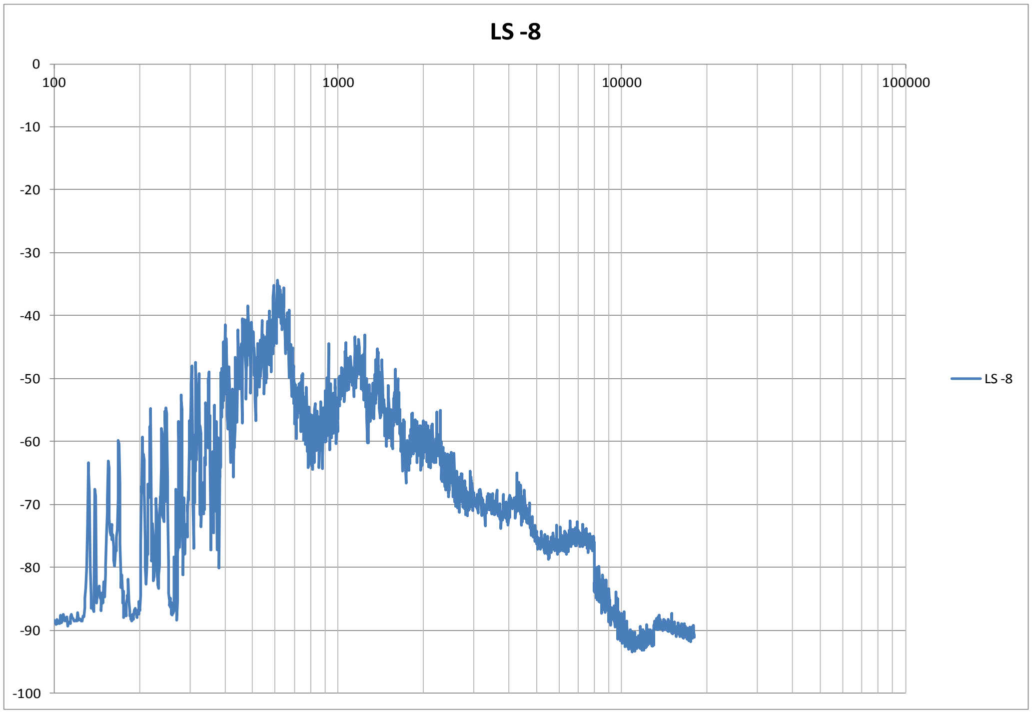


Figure F-7: Panel LS-8 shielding effectiveness data plot.

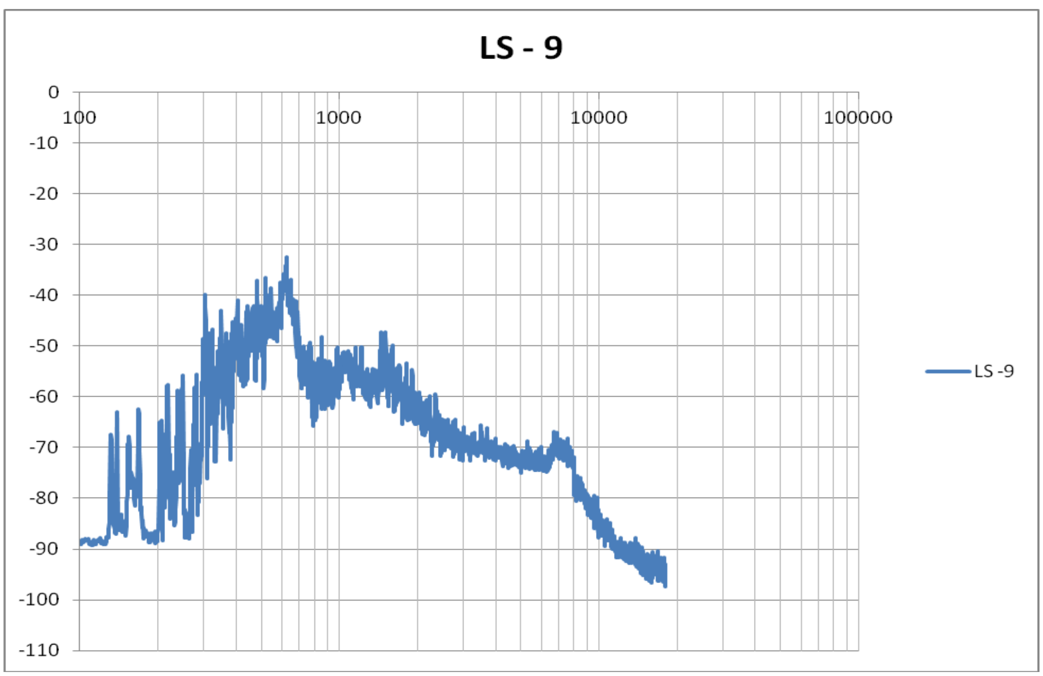


Figure F-8: Panel LS-9 shielding effectiveness test data.

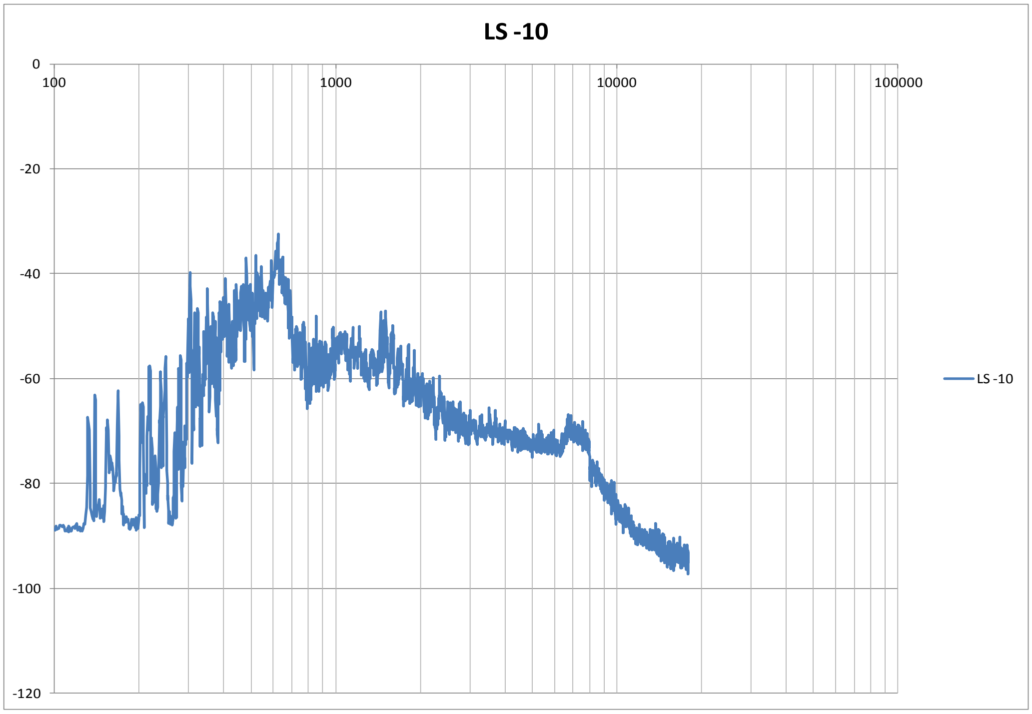


Figure F-9: Panel LS-10 shielding effectiveness data plot.

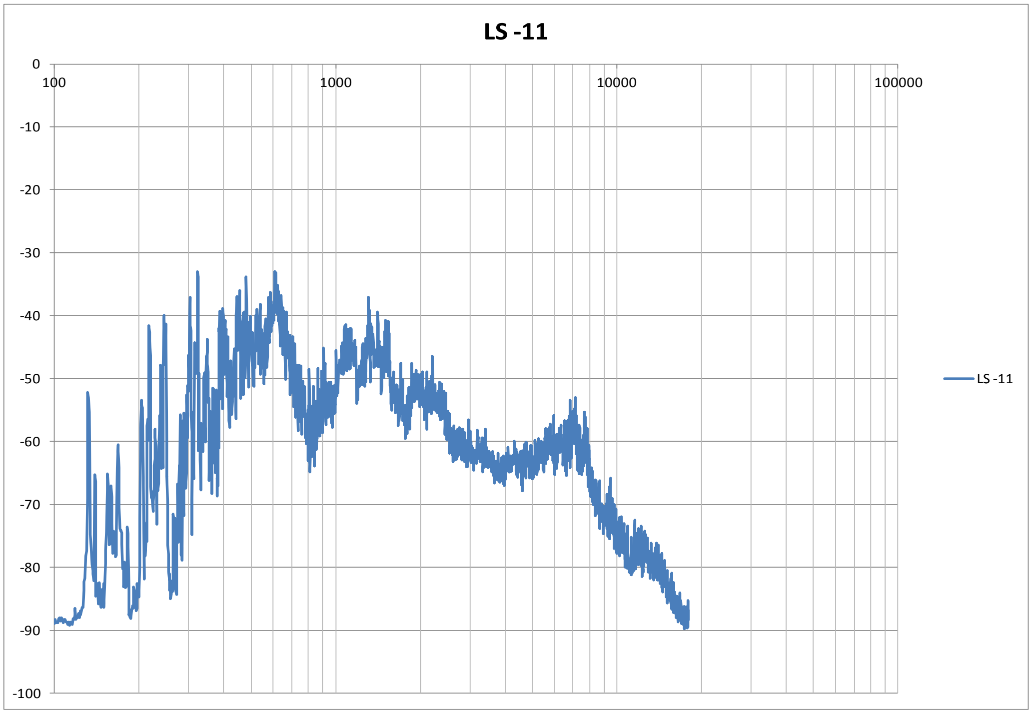


Figure F-10: Panel LS-11 shielding effectiveness data plot.

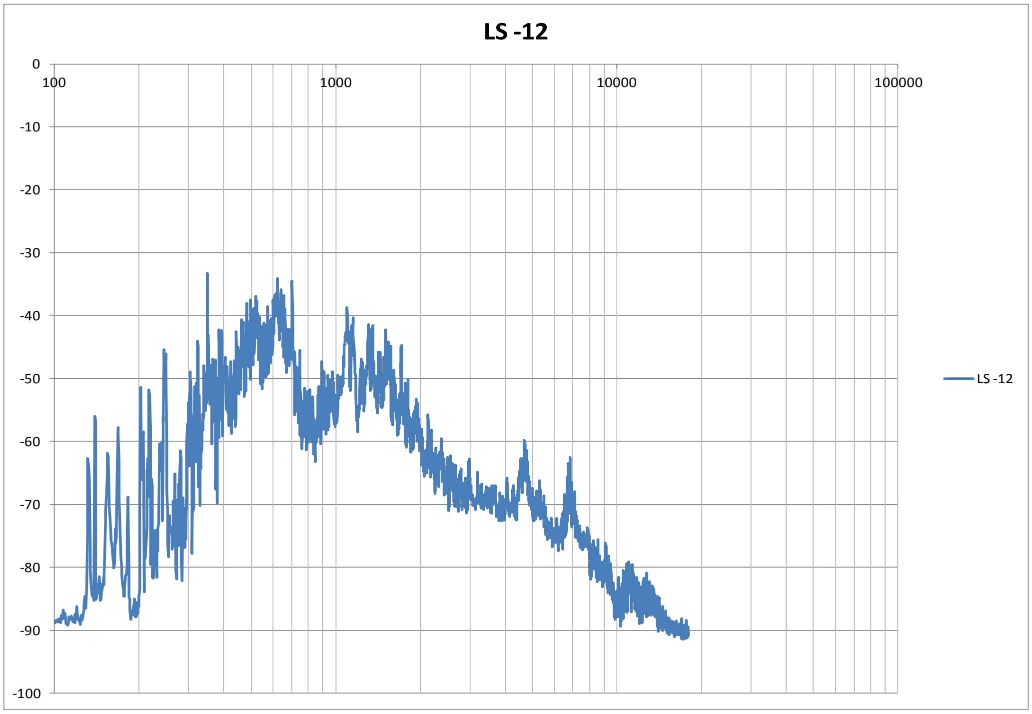


Figure F-11: Panel LS-12 shielding effectiveness data plot.

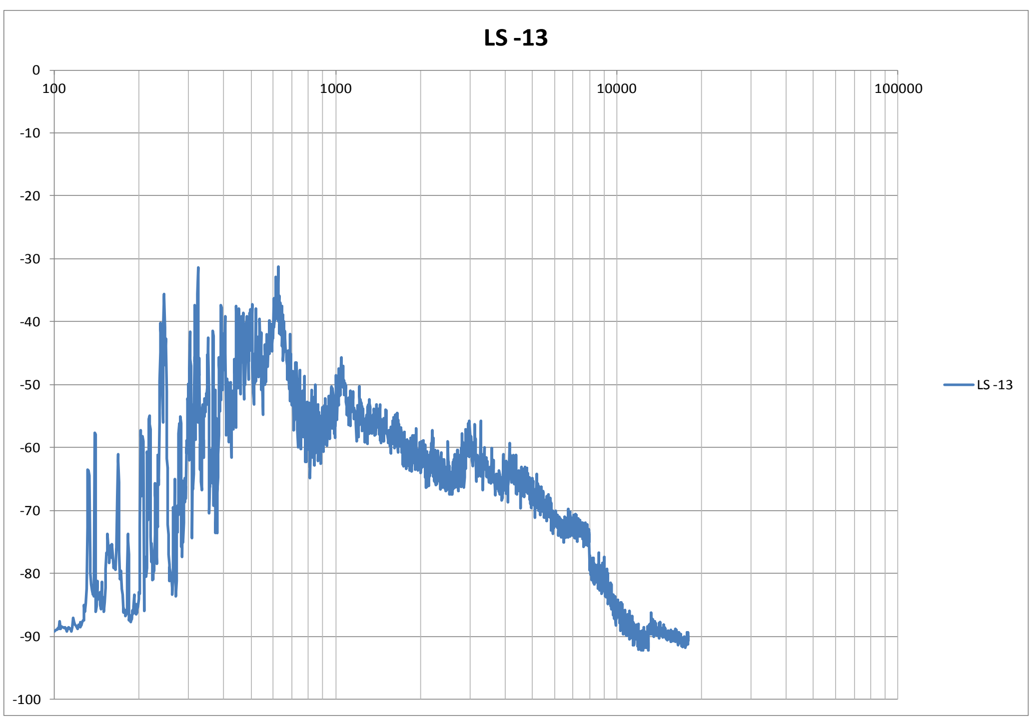


Figure F-12: Panel LS-13 shielding effectiveness data plot.

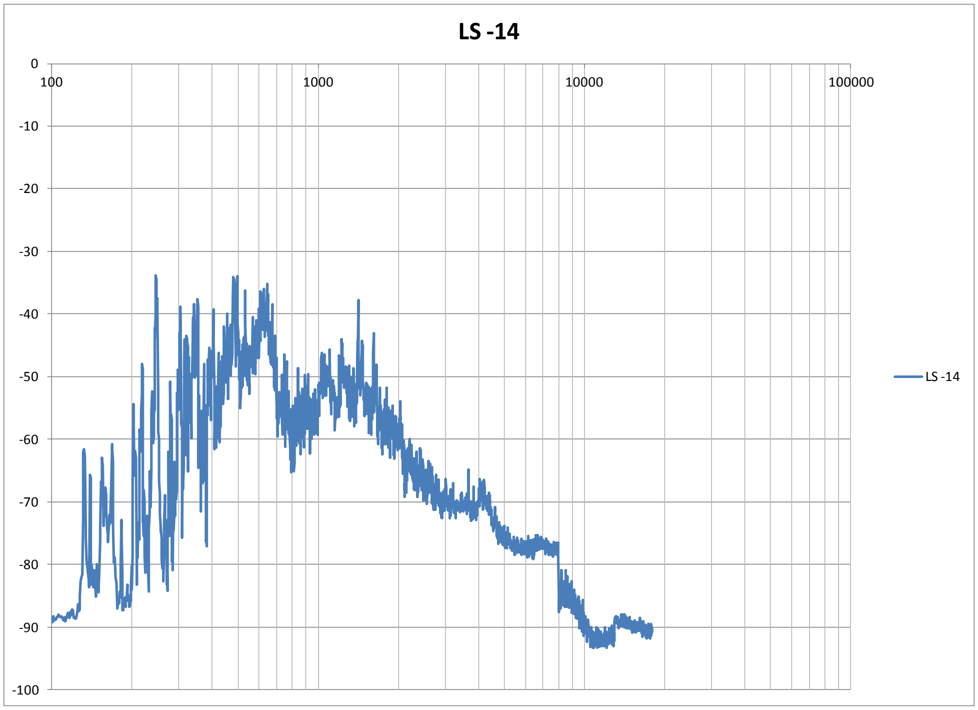


Figure F-13: Panel LS-14 shielding effectiveness data plot.

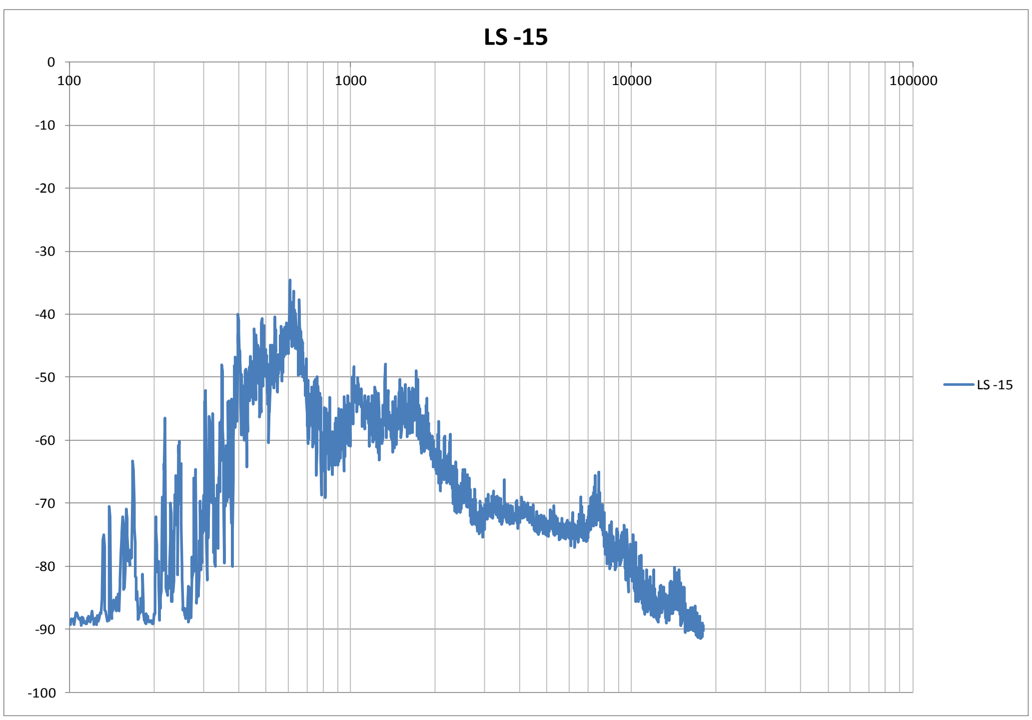


Figure F-14: Panel LS-15 shielding effectiveness data plot.

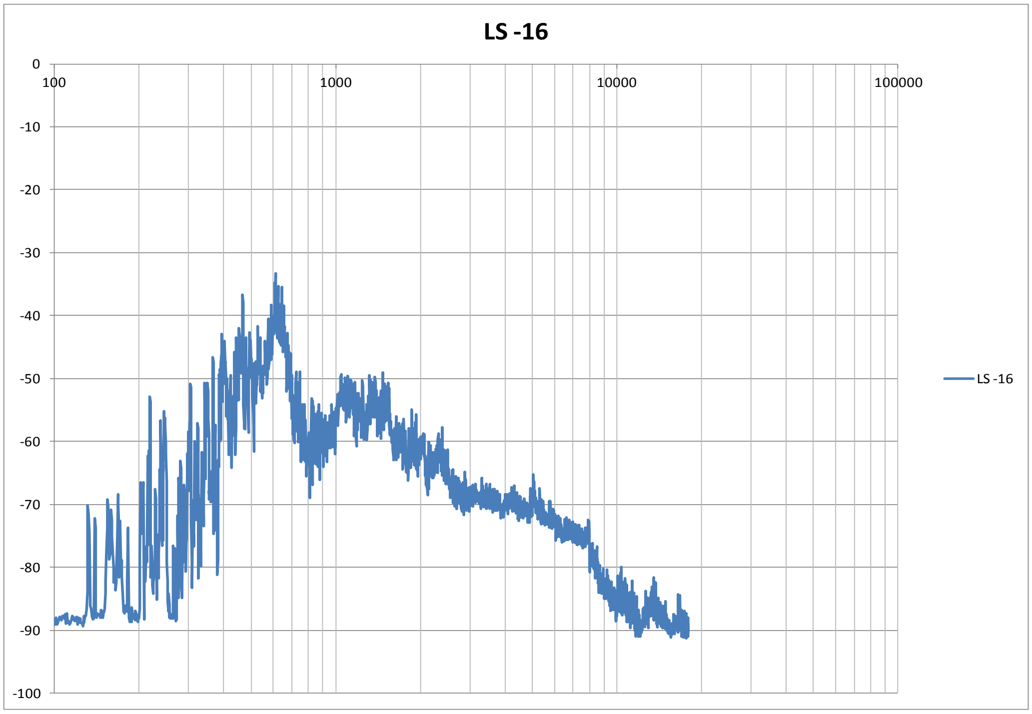


Figure F-15: Panel LS-16 shielding effectiveness data plot.

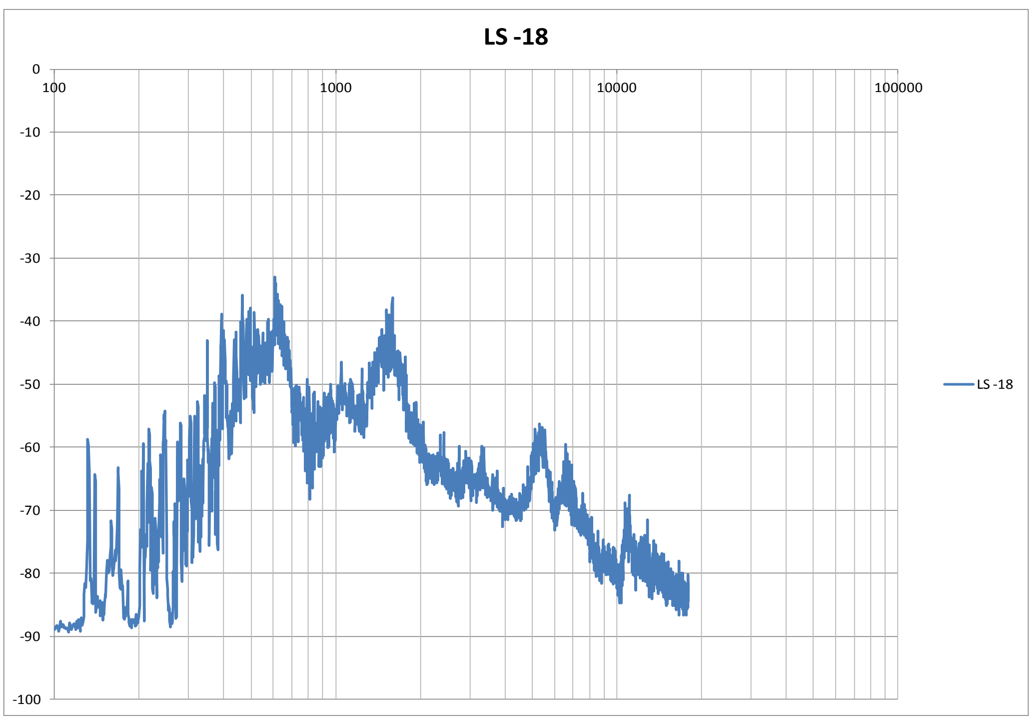


Figure F-16: Panel LS-18 shielding effectiveness data plot.

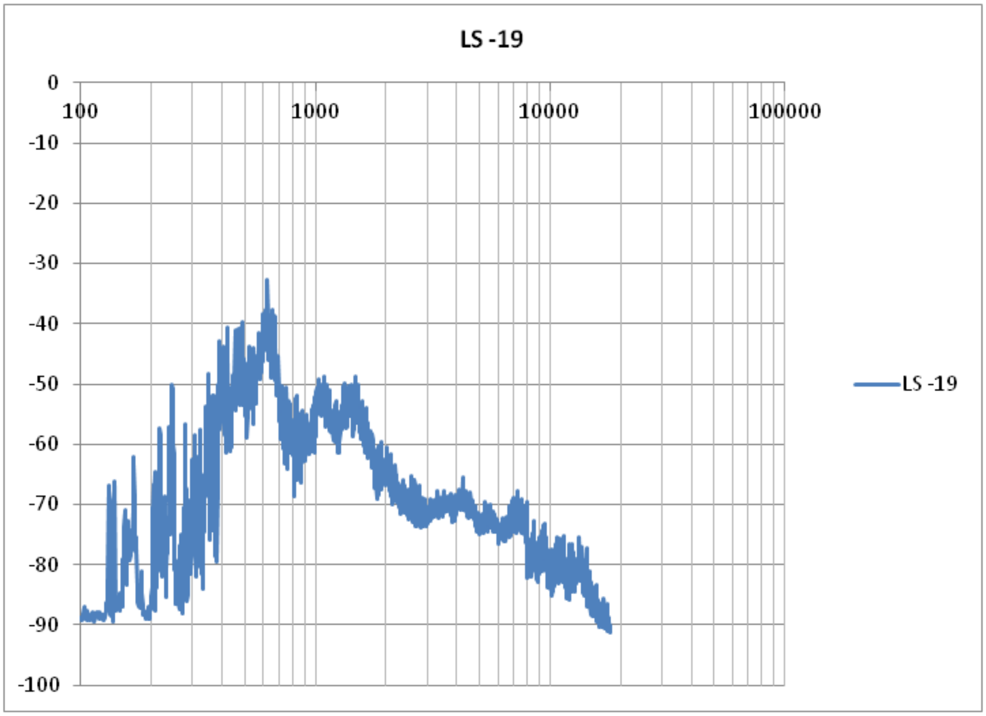


Figure F-17: Panel LS-19 shielding effectiveness test data.

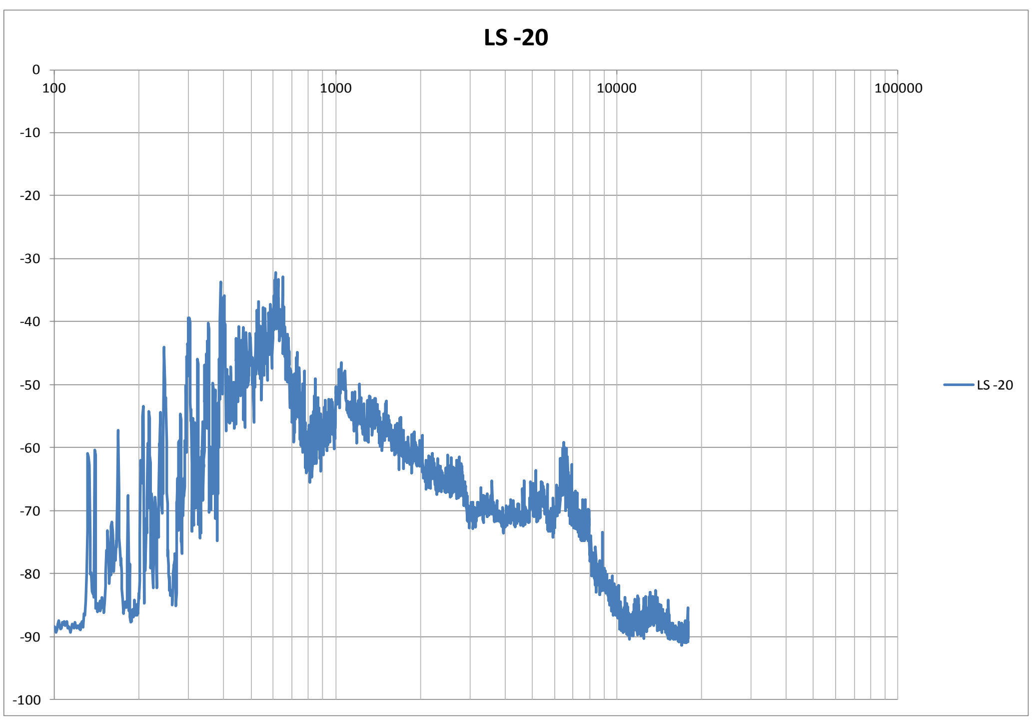


Figure F-18: Panel LS-20 shielding effectiveness test data.

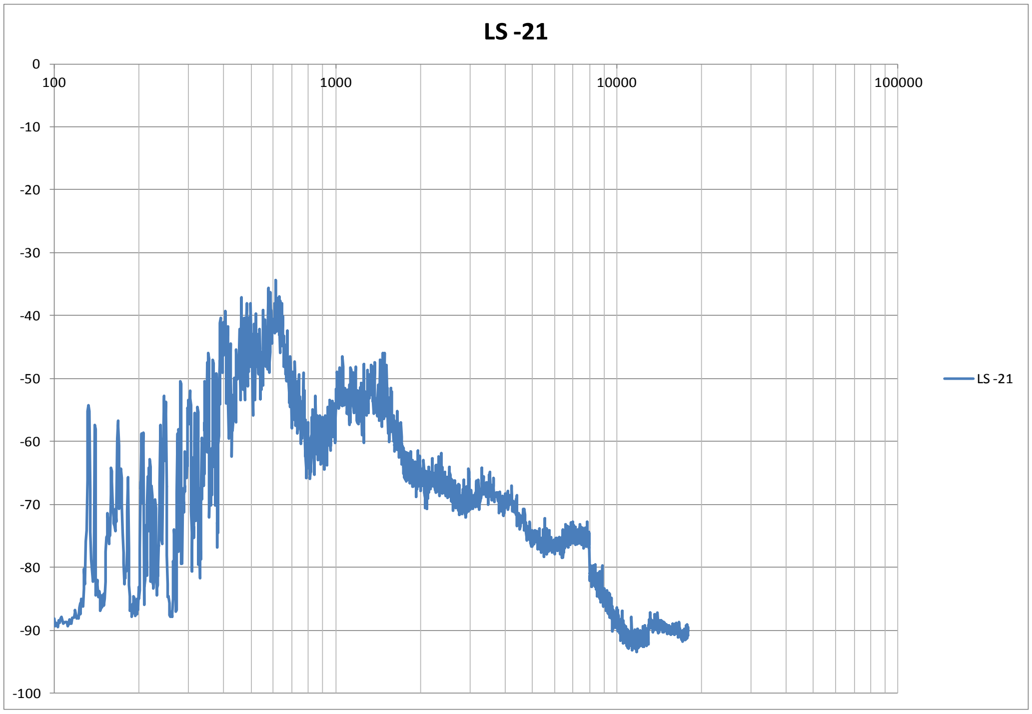


Figure F-19: Panel LS-21 shielding effectiveness test data.

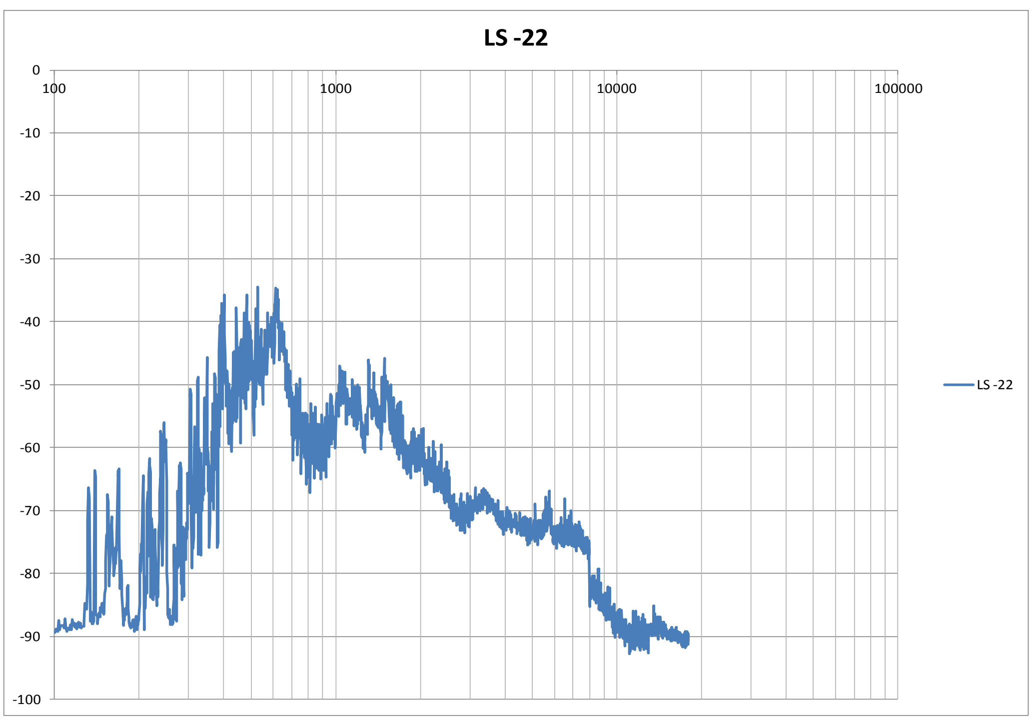


Figure F-20: Panel LS-22 shielding effectiveness test data.

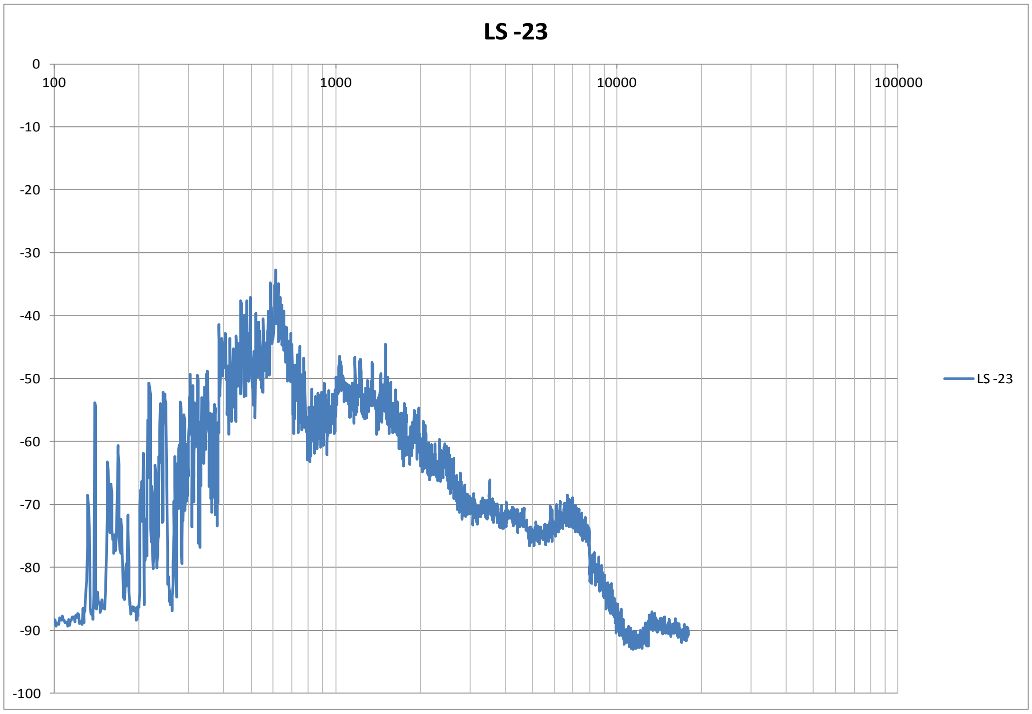


Figure F-21: Panel LS-23 shielding effectiveness data.

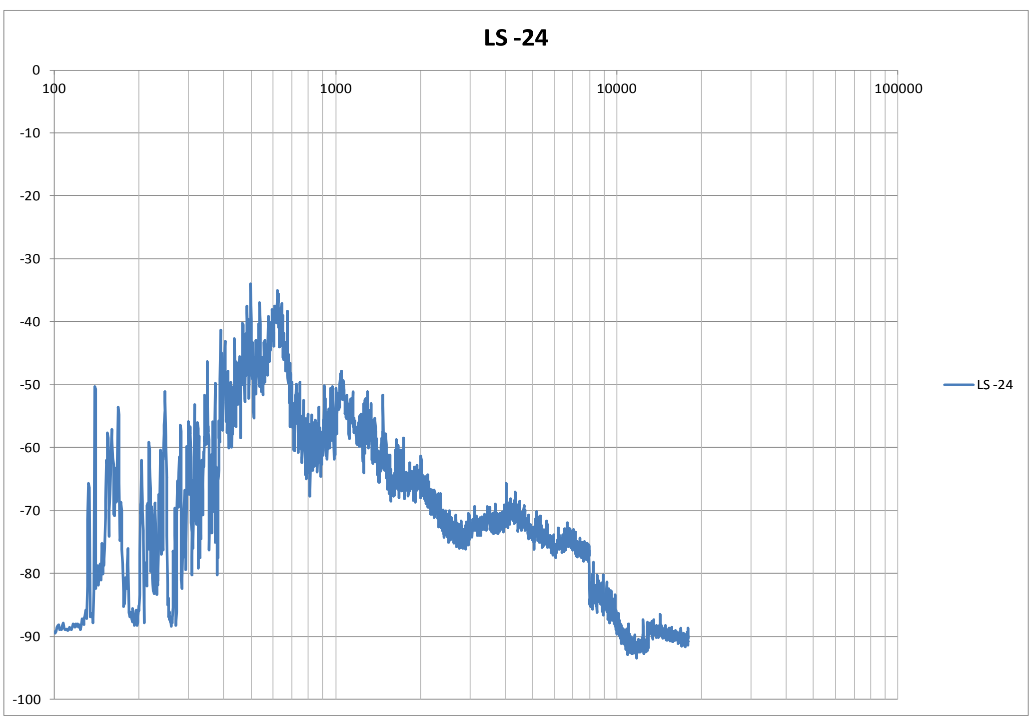


Figure F-22: Panel LS-24 shielding effectiveness test data.

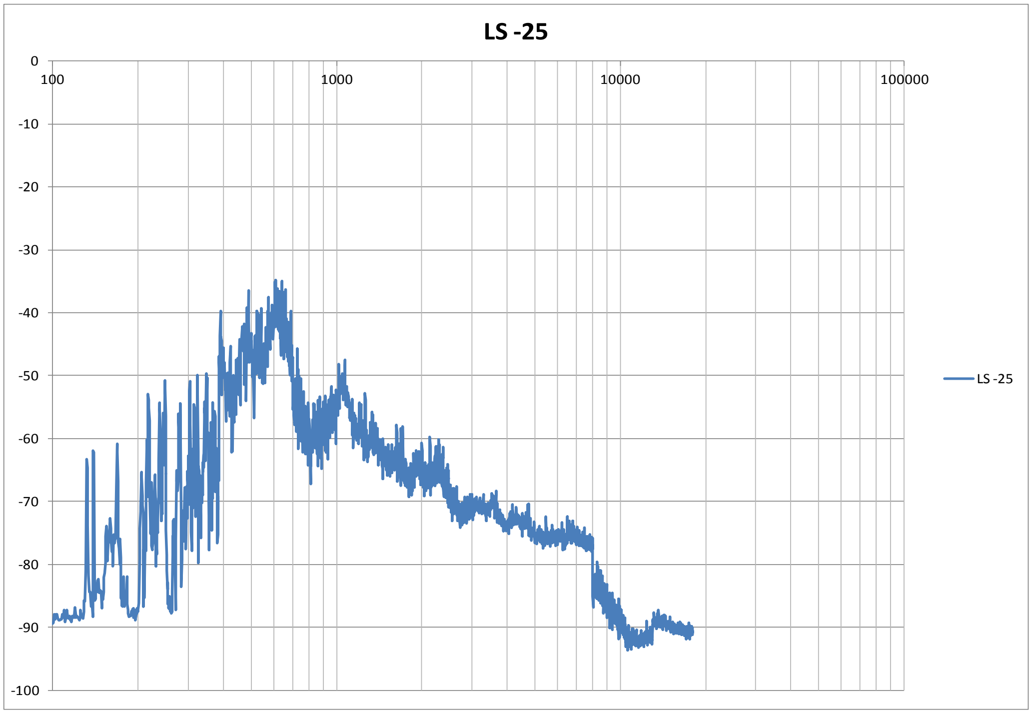


Figure F-23: Panel LS-25 shielding effectiveness test data.

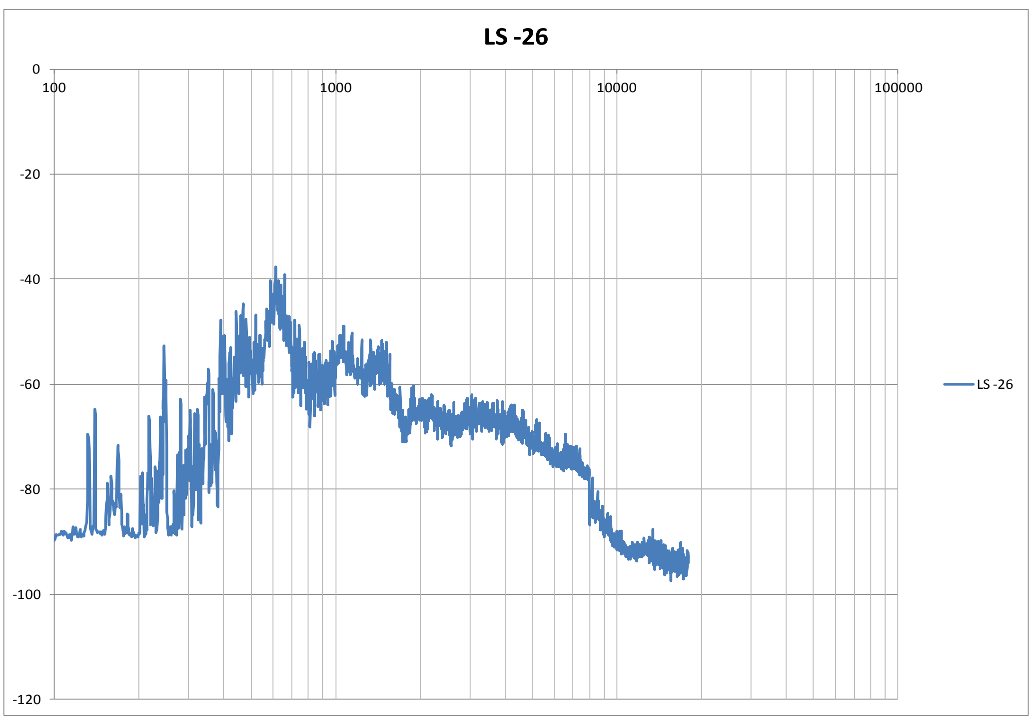


Figure F-24: Panel LS-26 shielding effectiveness test data.

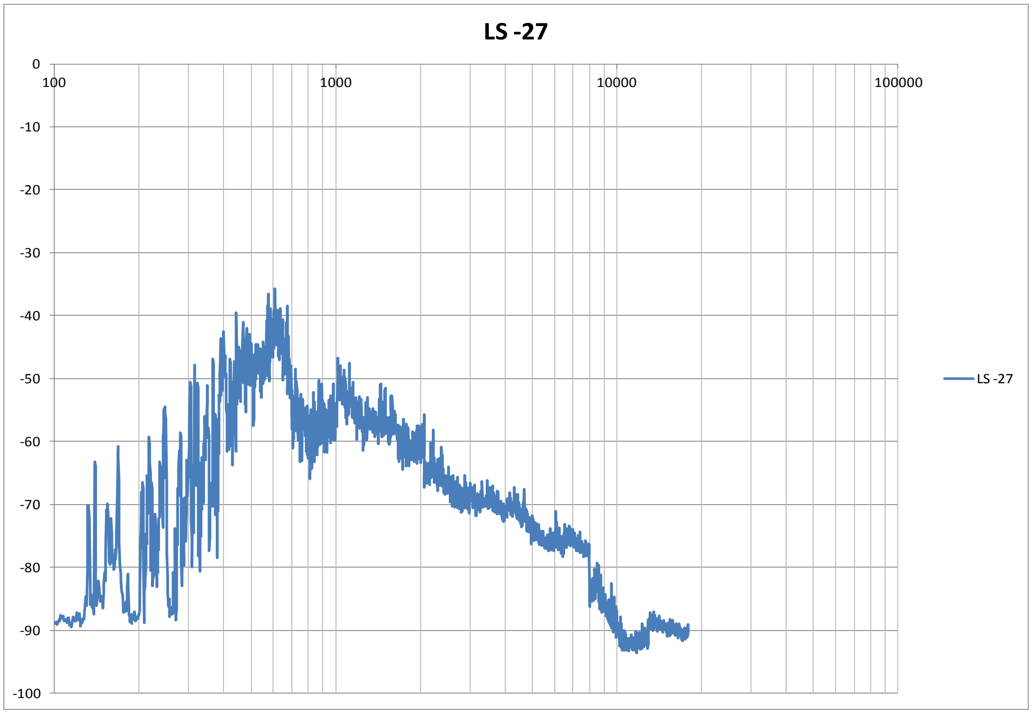


Figure F-25: Panel LS-27 shielding effectiveness test data.

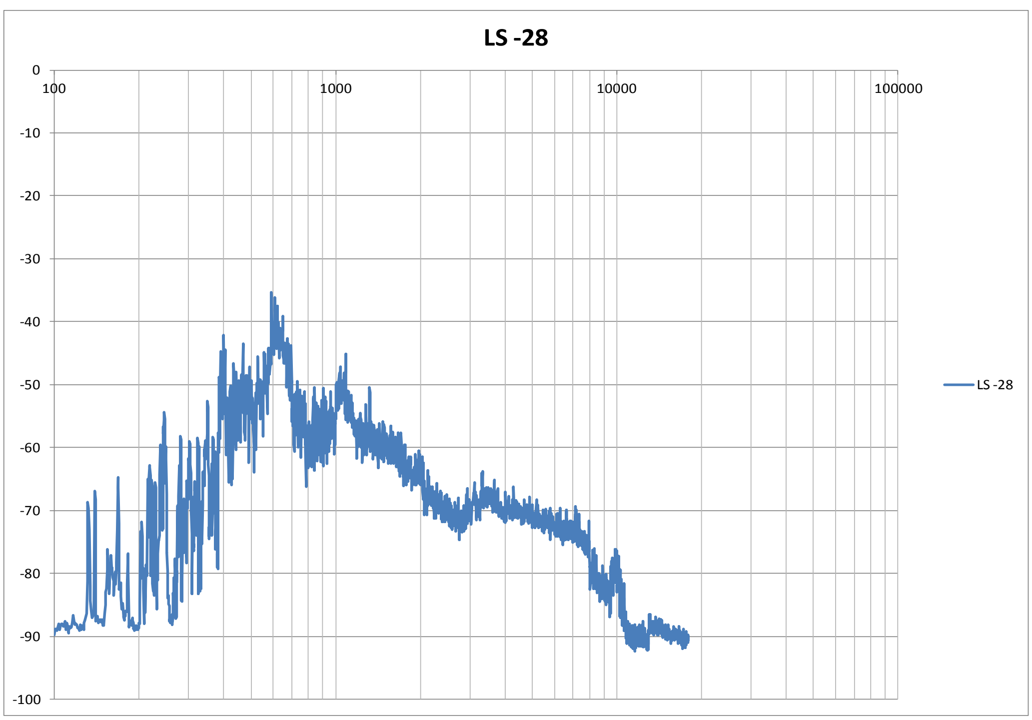


Figure F-26: Panel LS-28 shielding effectiveness test data.

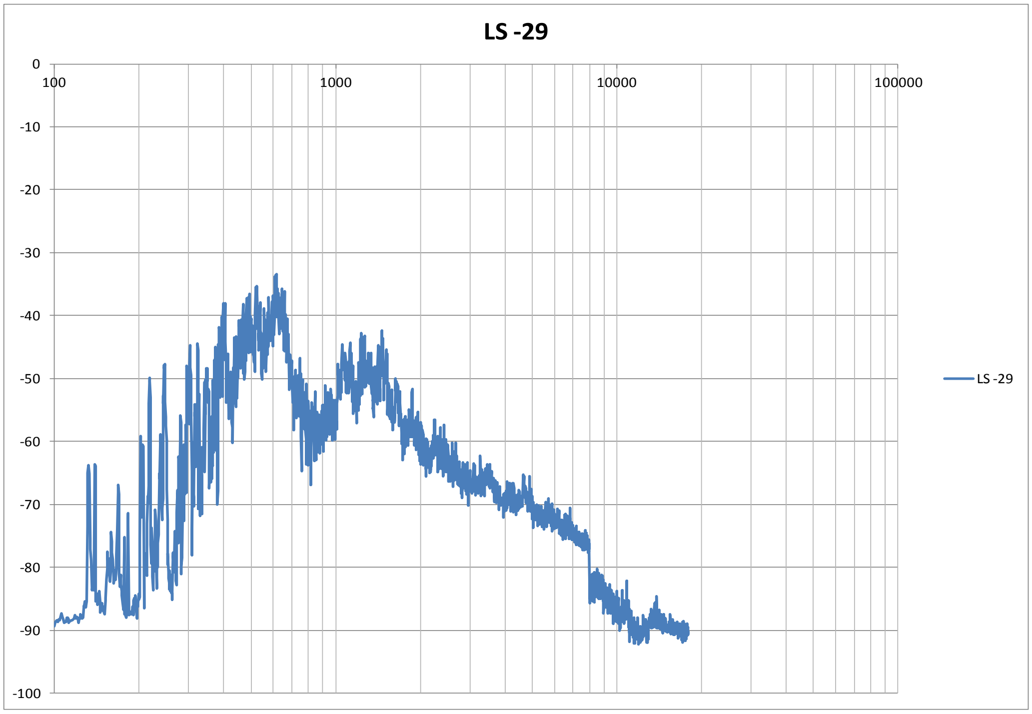


Figure F-27: Panel LS-29 shielding effectiveness test data.

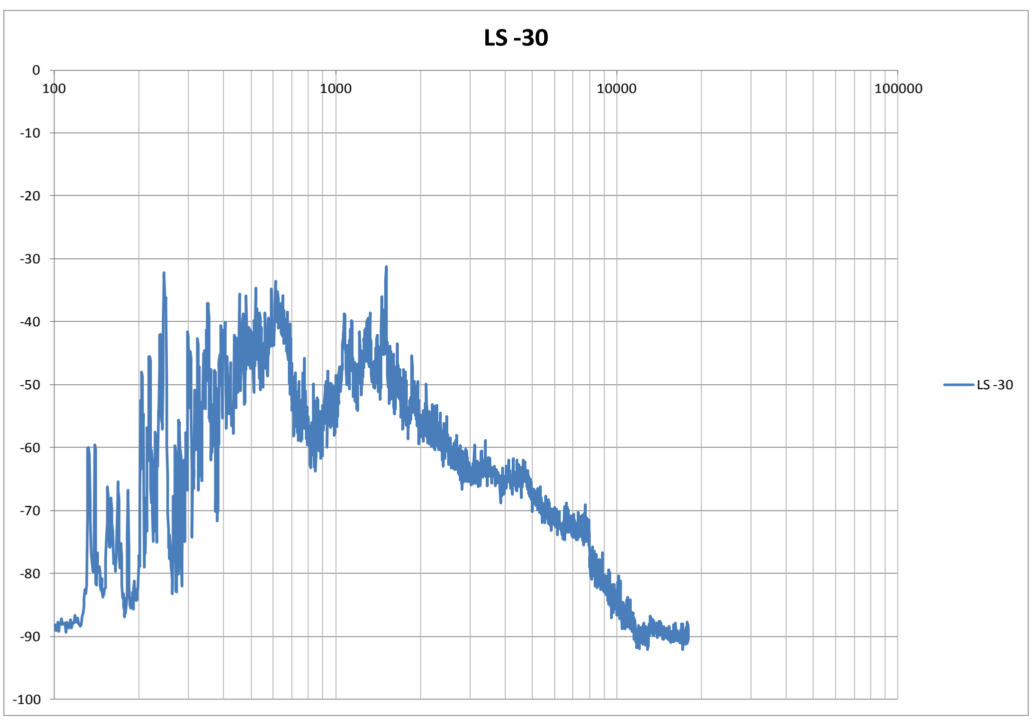


Figure F-28: Panel LS-30 shielding effectiveness test data.

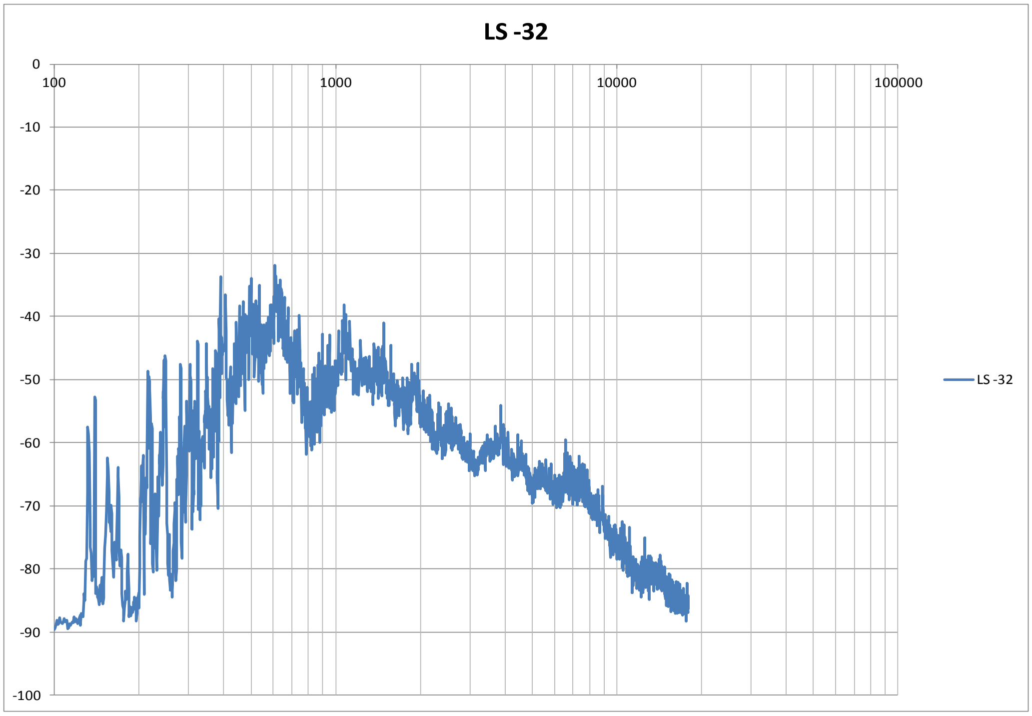


Figure F-29: Panel LS-32 shielding effectiveness test data.

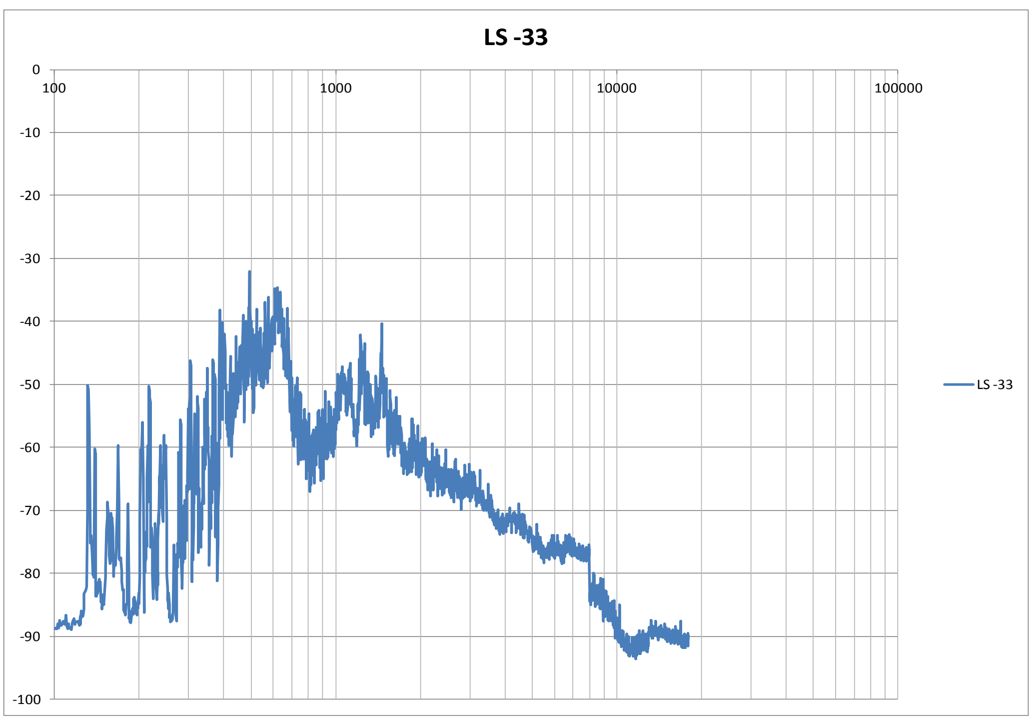


Figure F-30: Panel LS-33 shielding effectiveness test data.

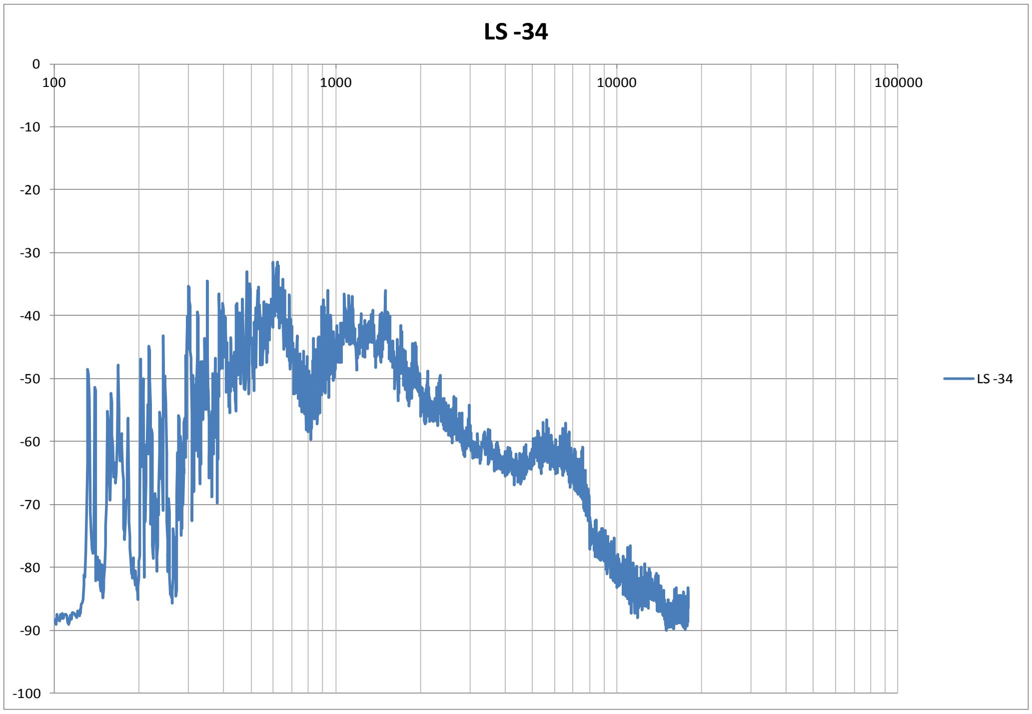


Figure F-31: Panel LS-34 shielding effectiveness test data.

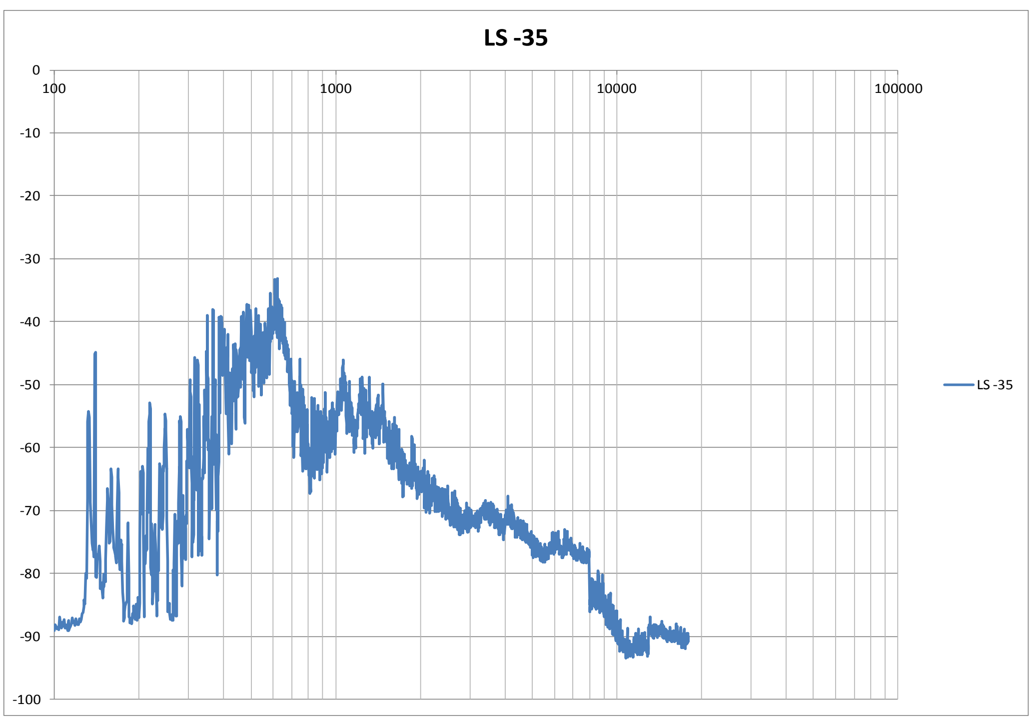


Figure F-32: Panel LS-35 shielding effectiveness test data.

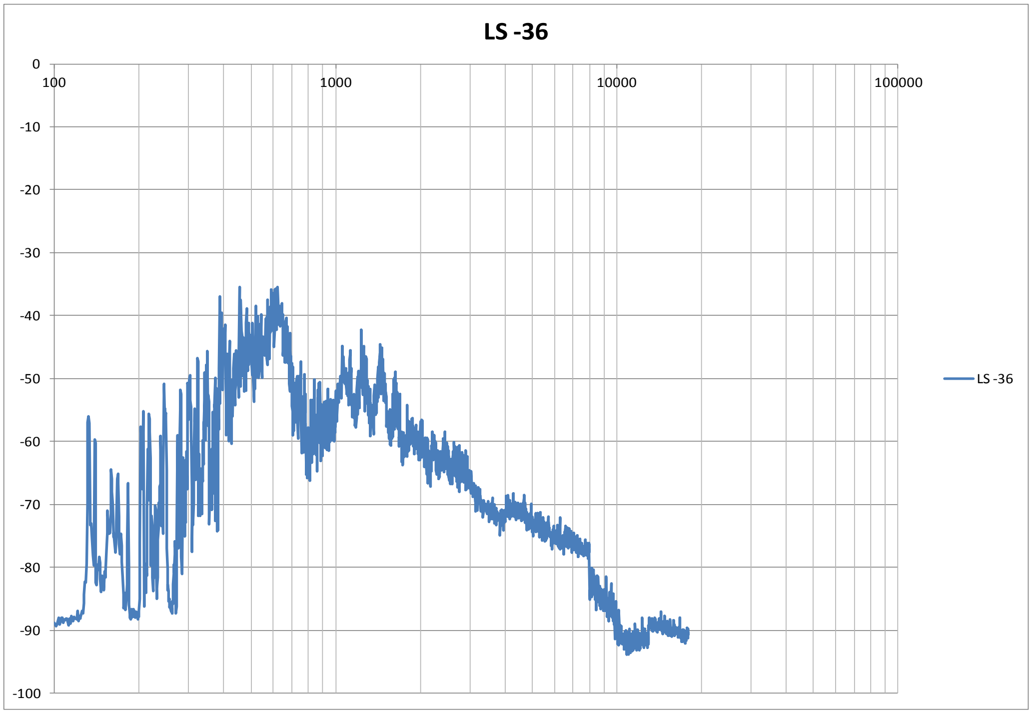


Figure F-33: Panel LS-36 shielding effectiveness test data.

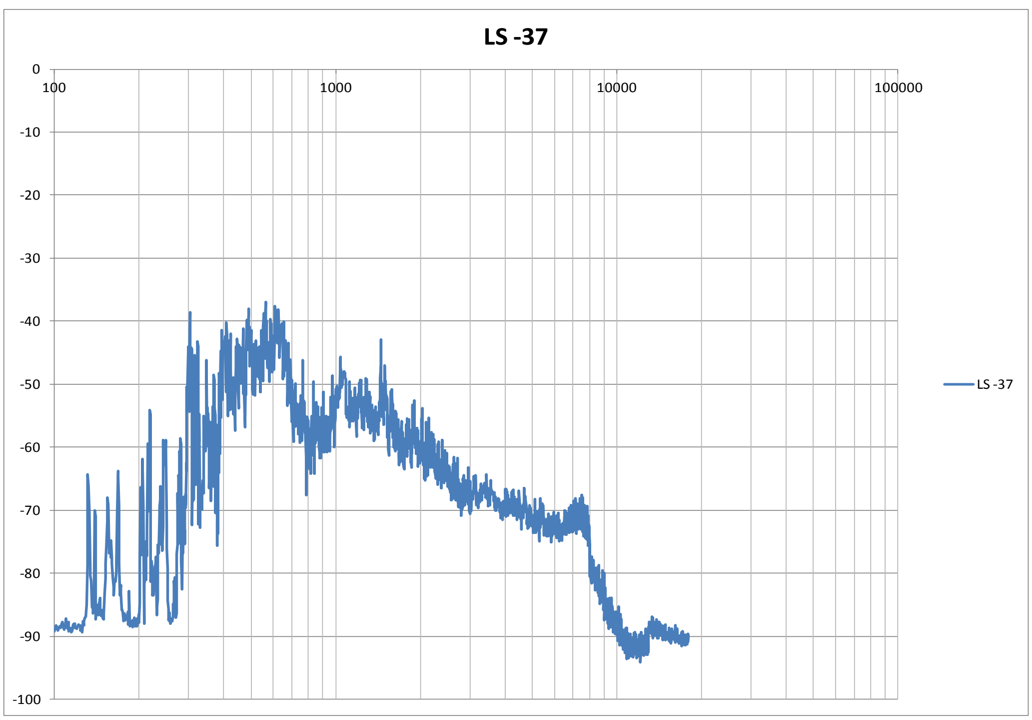


Figure F-34: Panel LS-37 shielding effectiveness test data.

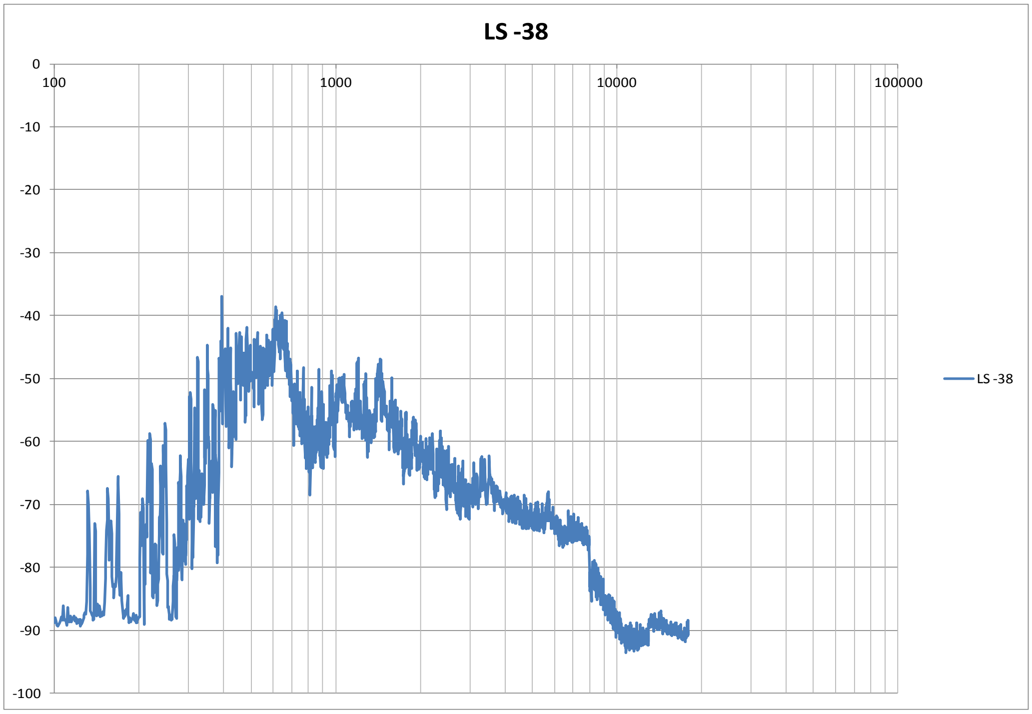


Figure F-35: Panel LS-38 shielding effectiveness test data.

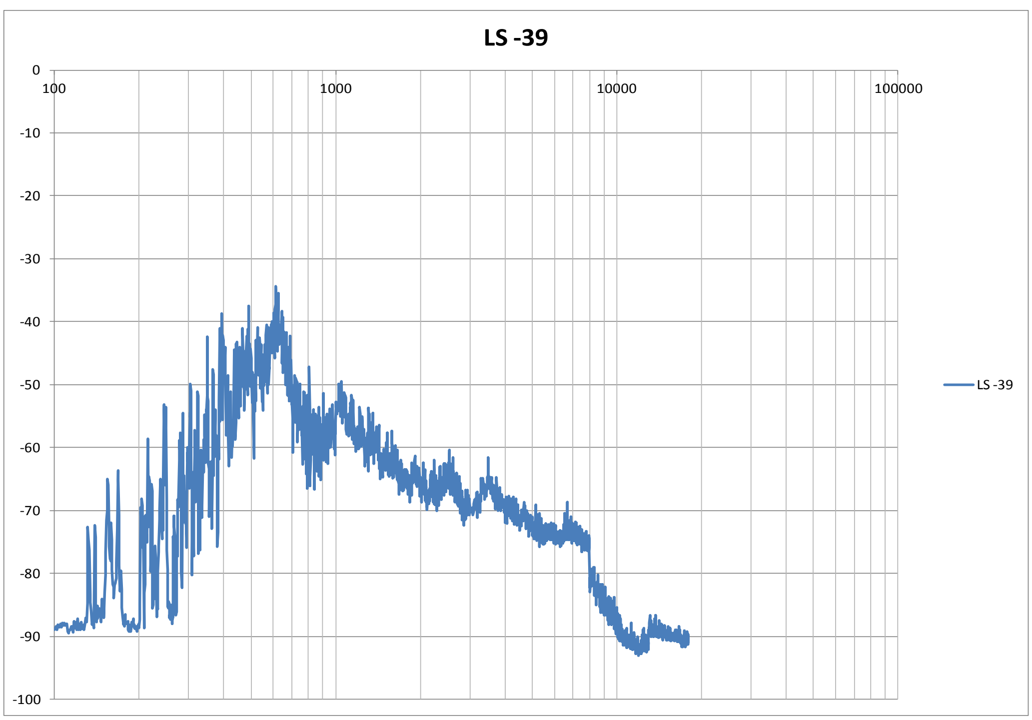


Figure F-36: Panel LS-39 shielding effectiveness test data.

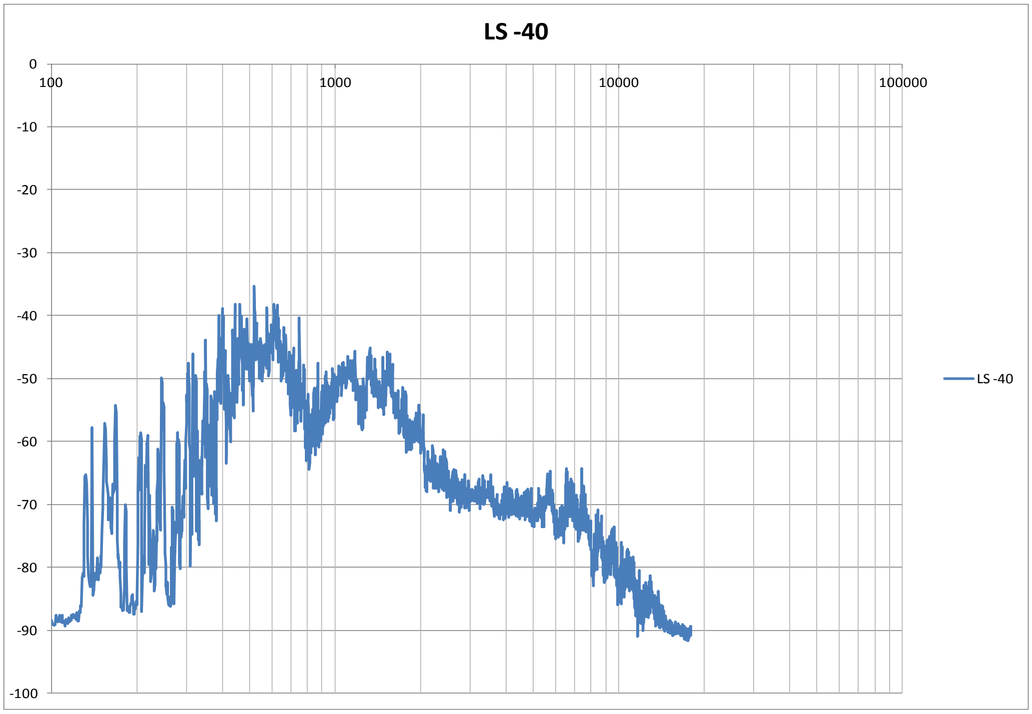


Figure F-37: Panel LS-40 shielding effectiveness test data.

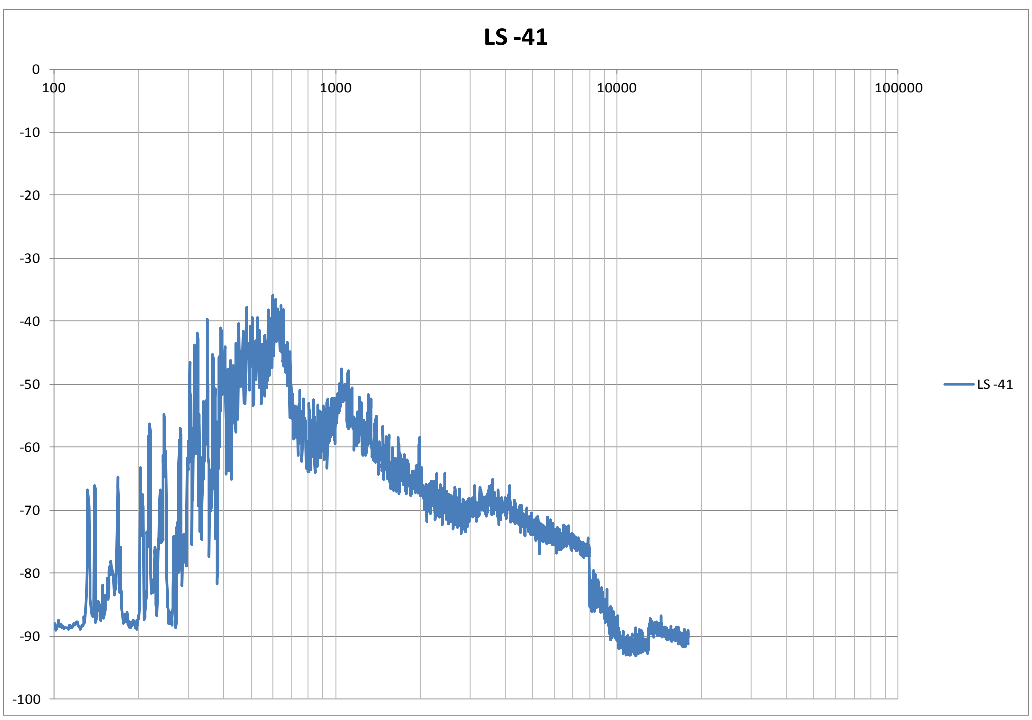


Figure F-38: Panel LS-41 shielding effectiveness test data.

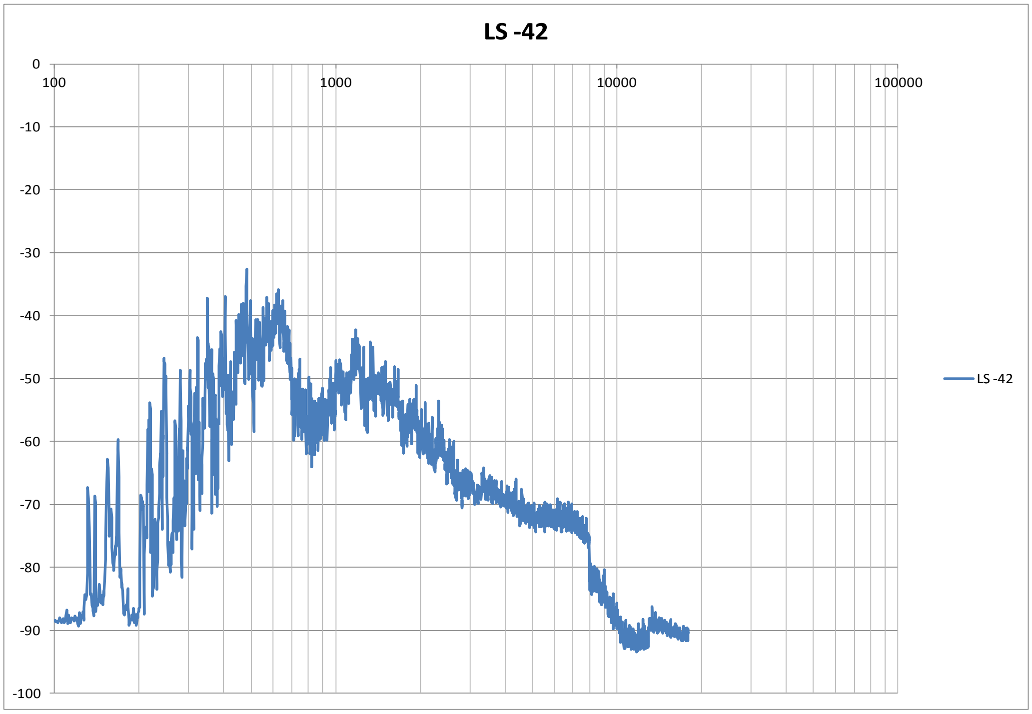


Figure F-39: Panel LS-42 shielding effectiveness data.

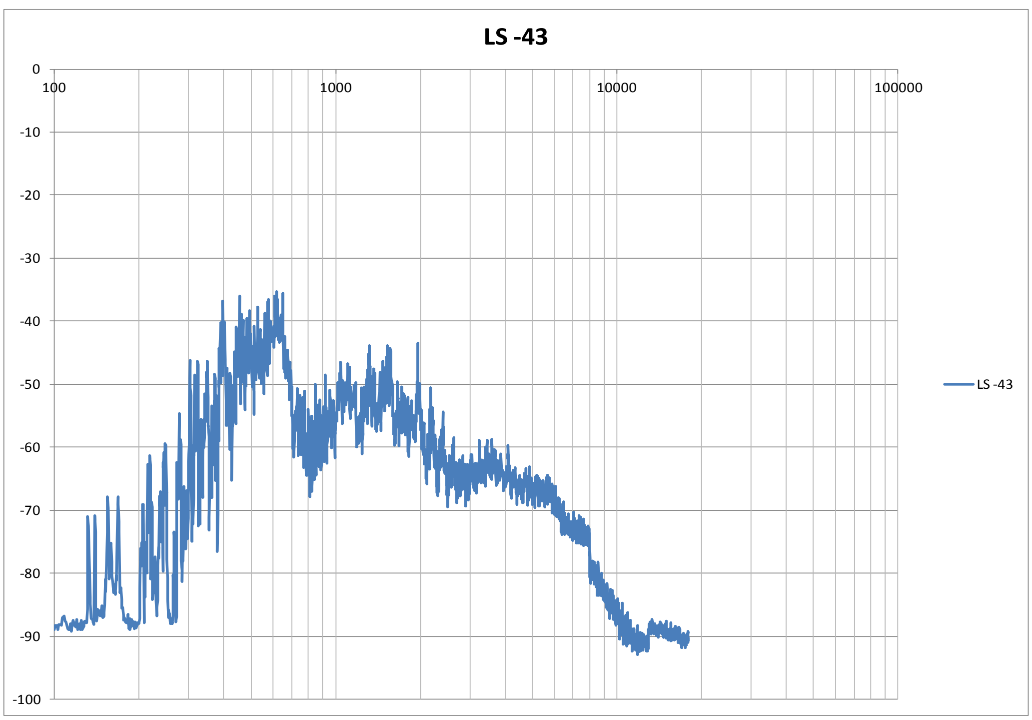


Figure F-40: Panel LS-43 shielding effectiveness test data.

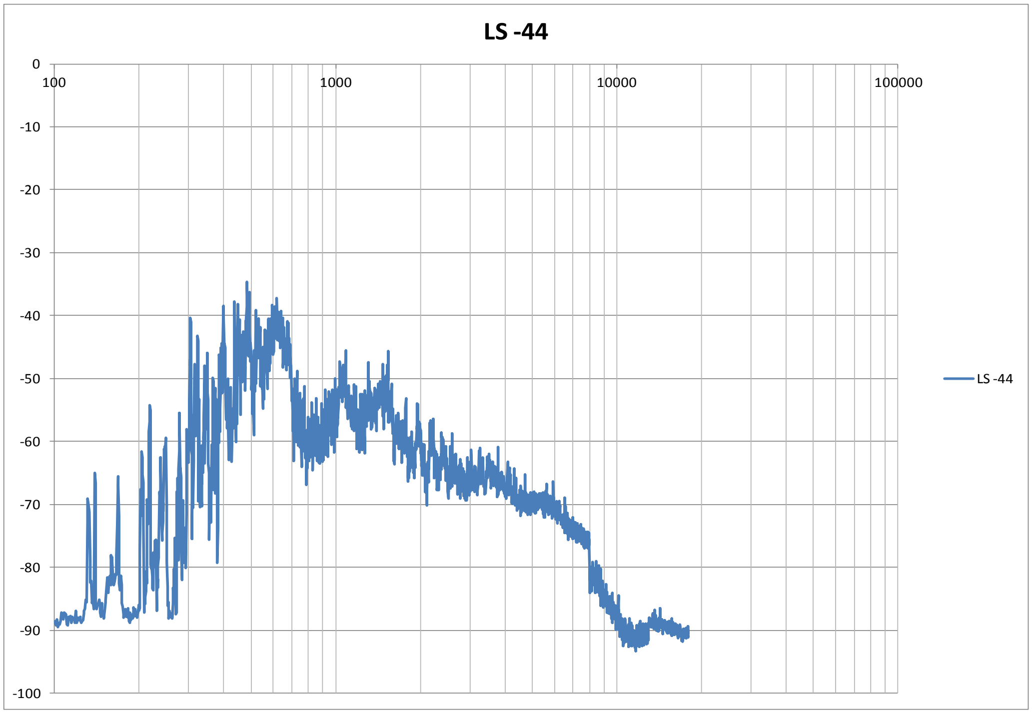


Figure F-41: Panel LS-44 shielding effectiveness data.

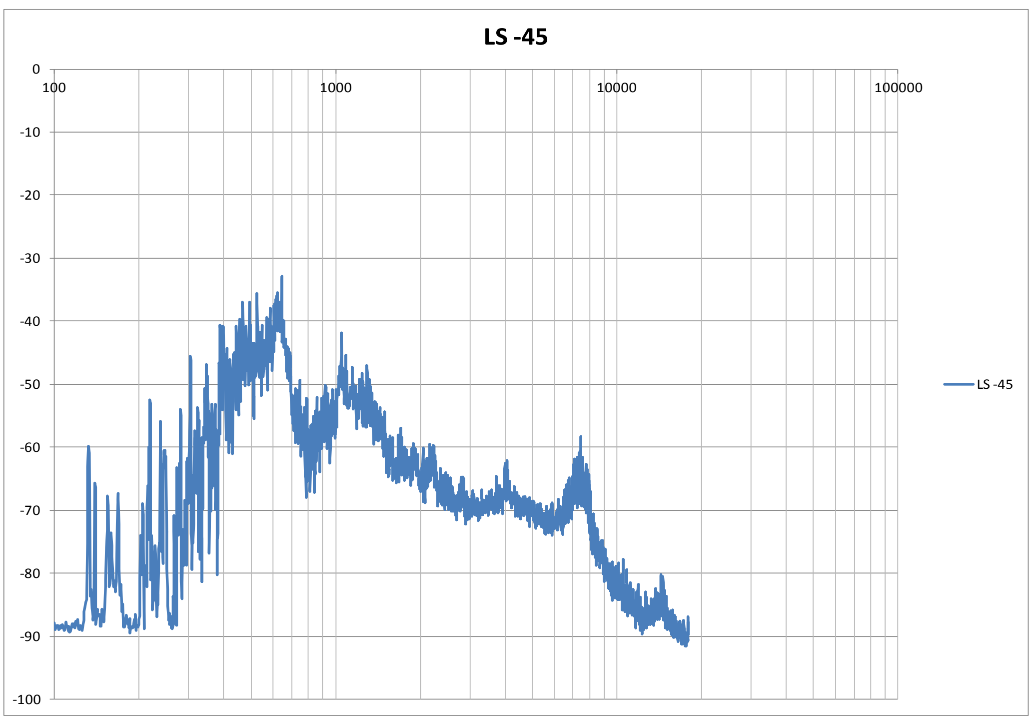


Figure F-42: Panel LS-45 shielding effectiveness data.

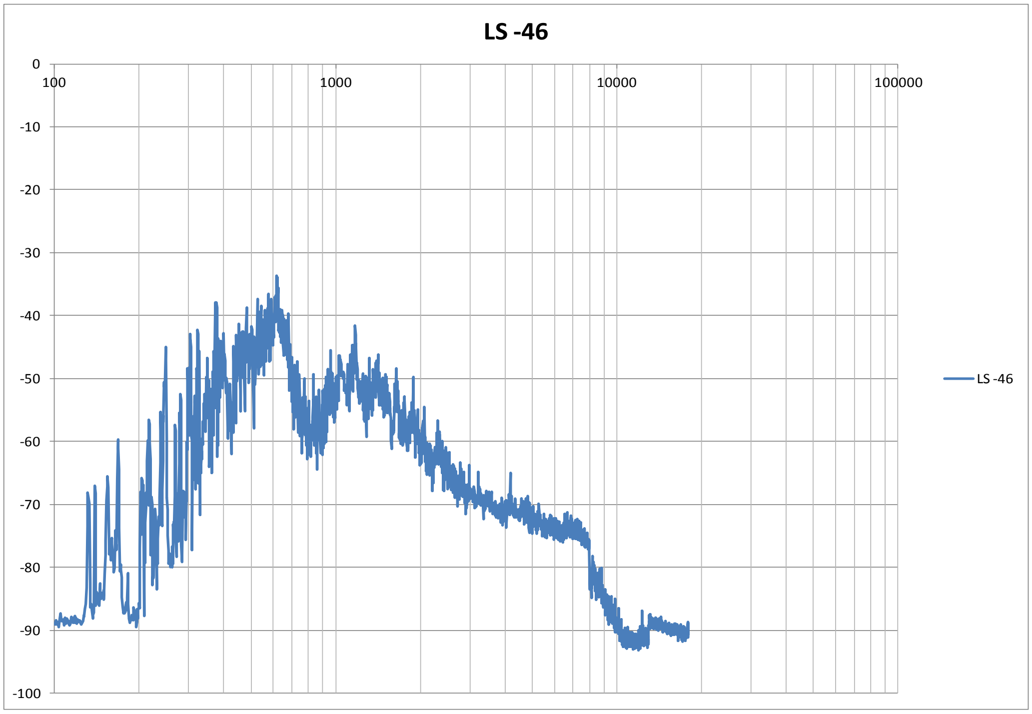


Figure F-43: Panel LS-46 shielding effectiveness test data.

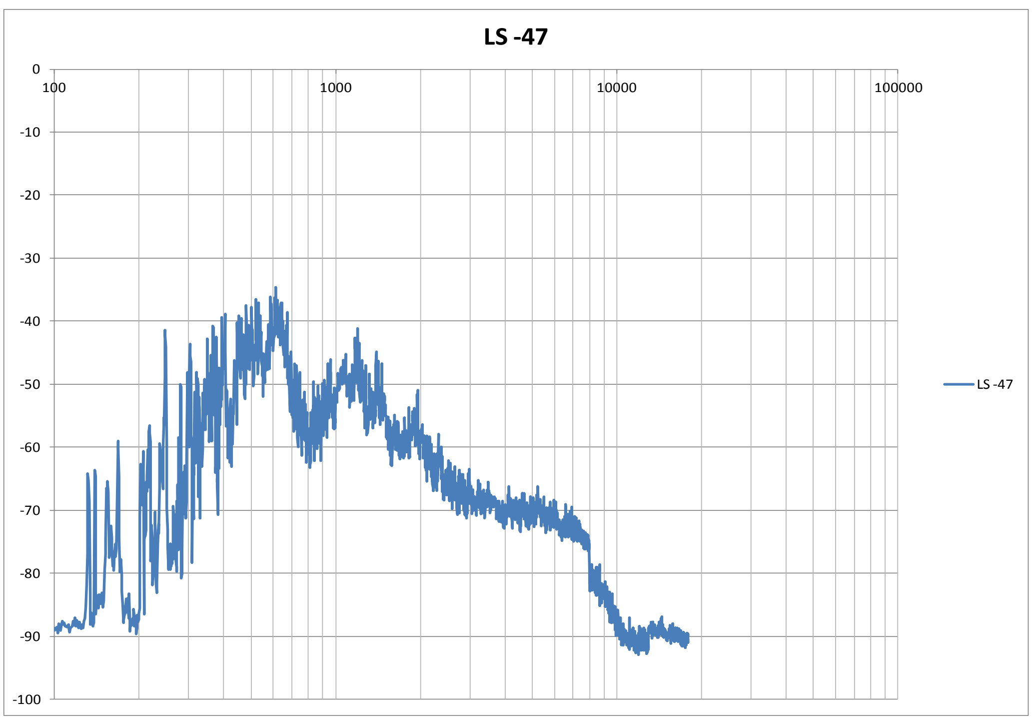


Figure F-44: Panel LS-47 shielding effectiveness test data.

APPENDIX G
First-Generation Indirect Effects Test Data (RTCA/DO-160F Section 22.0)

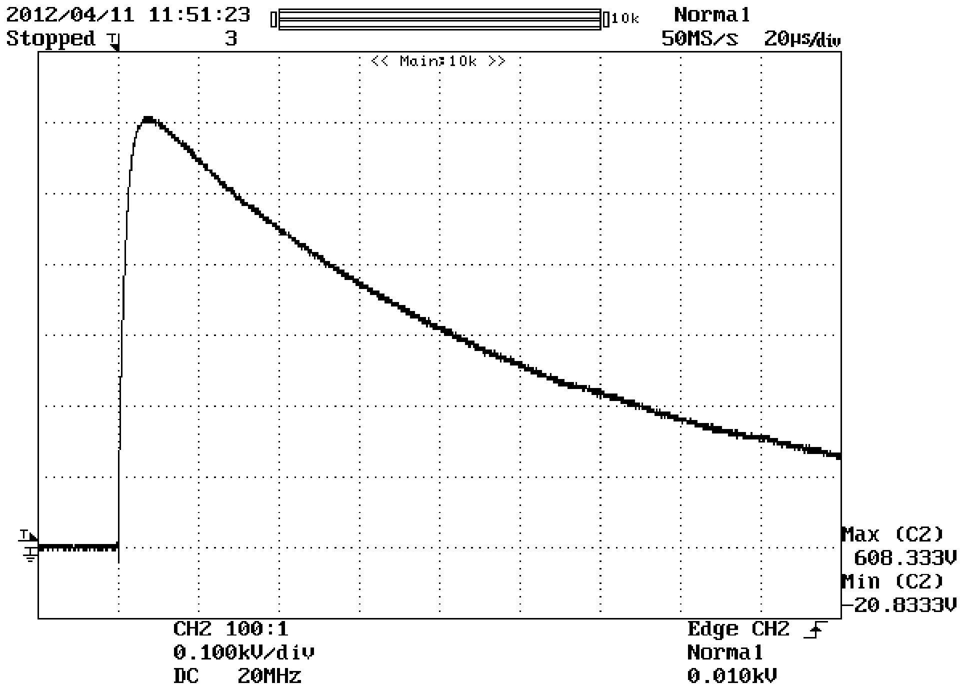


Figure G-45: Isc calibration WVFM 1 level 3 Pos 608 A (file 000).

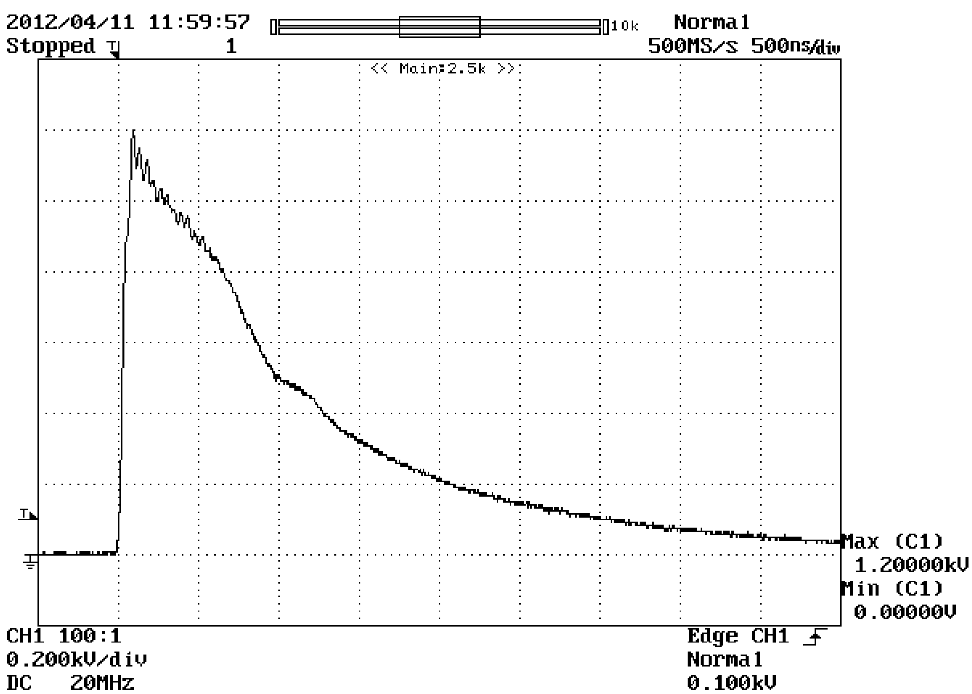


Figure G-46: Voc Calibration WVFM 2 level 3 Pos 1.2 kV (file 001).

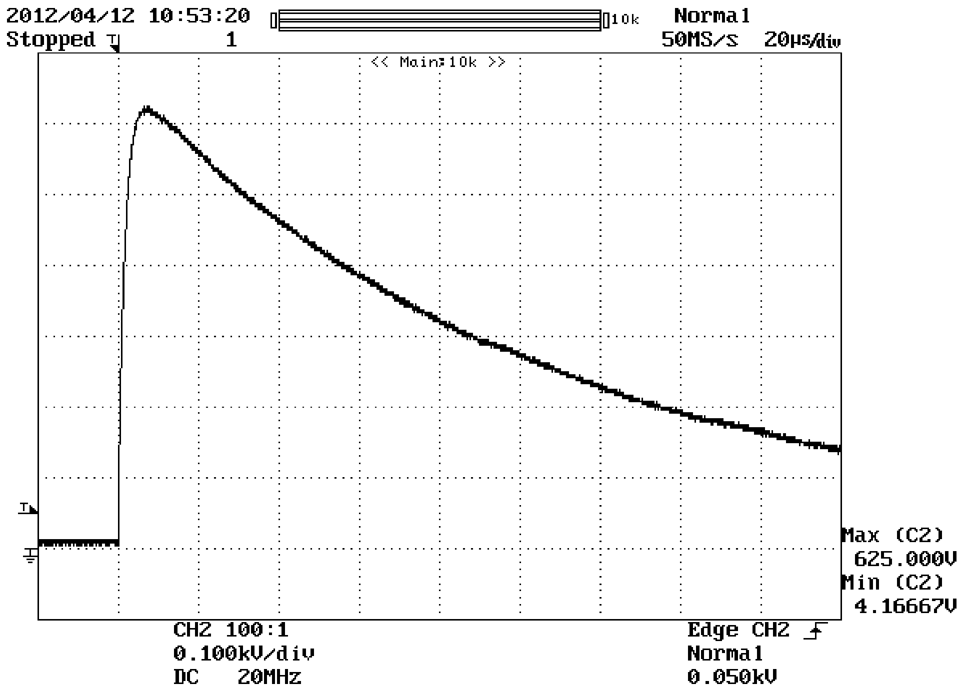


Figure G-47: isc(file 034)

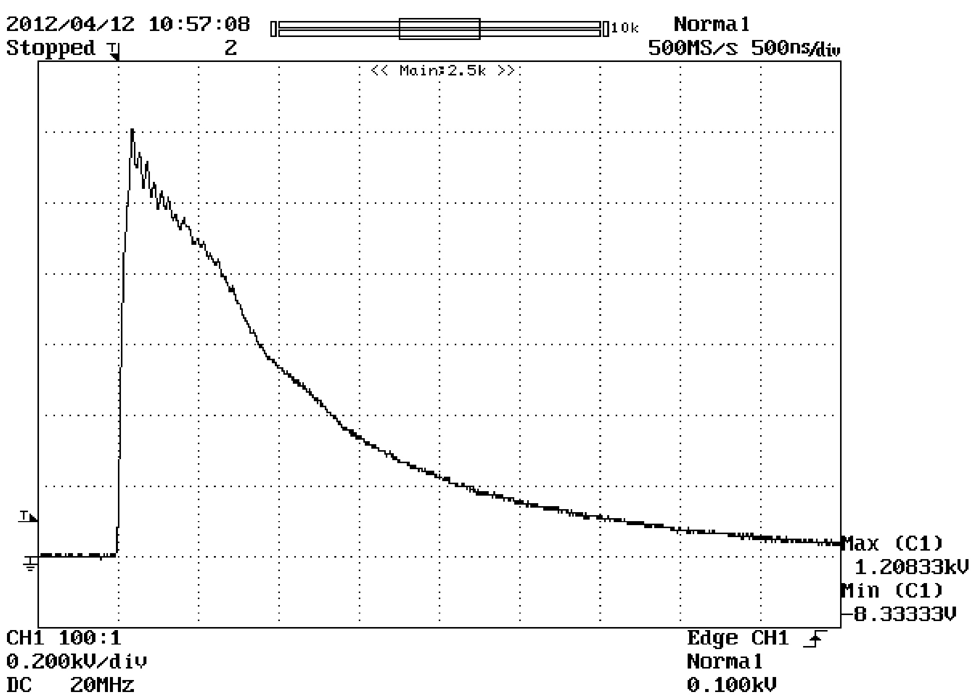


Figure G-48: voc (file 035).

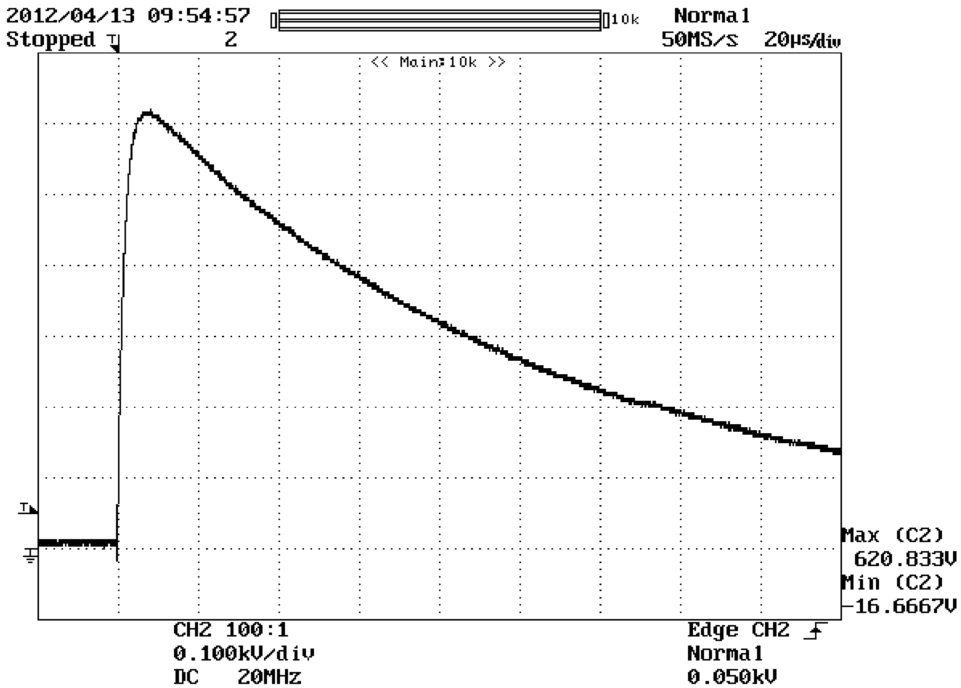


Figure G-49: Isc (file 068).

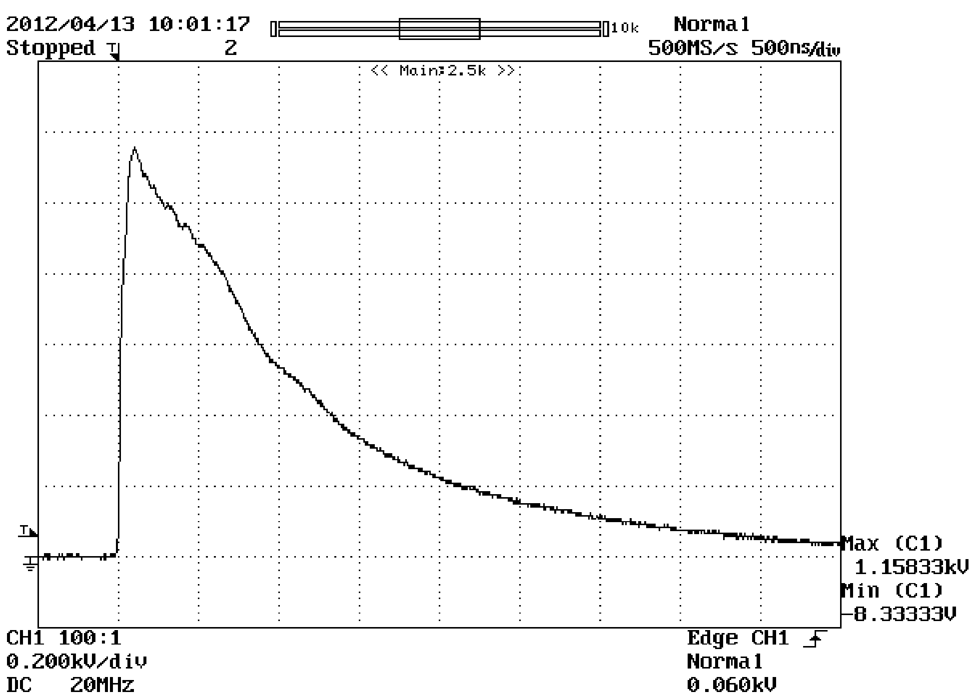


Figure G-50: Voc (file 069).

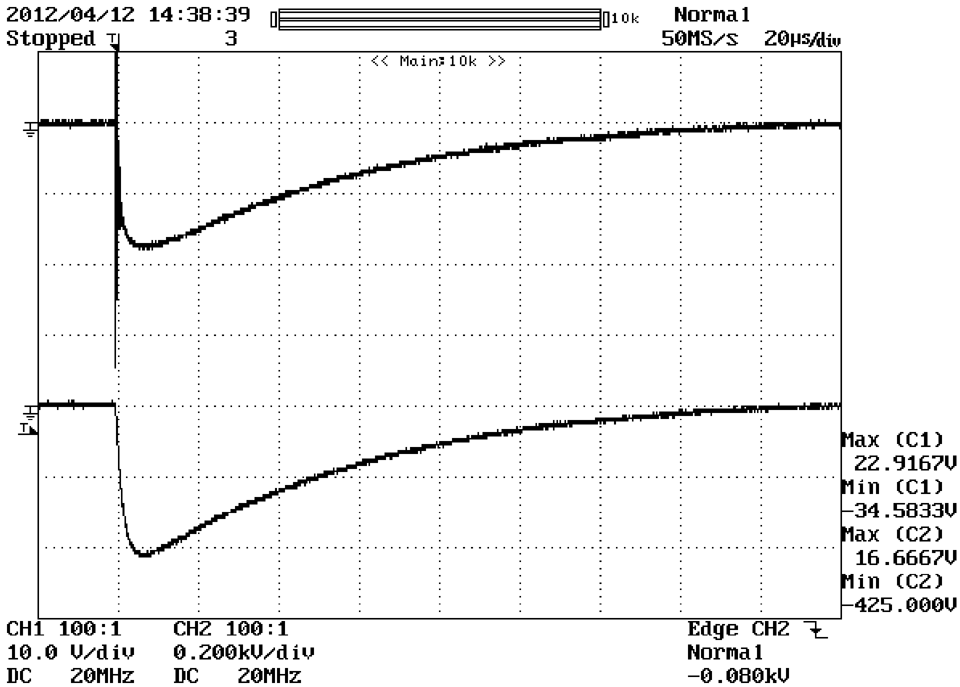


Figure G-51: Al Panel Neg -425 A 0.97(file 046).

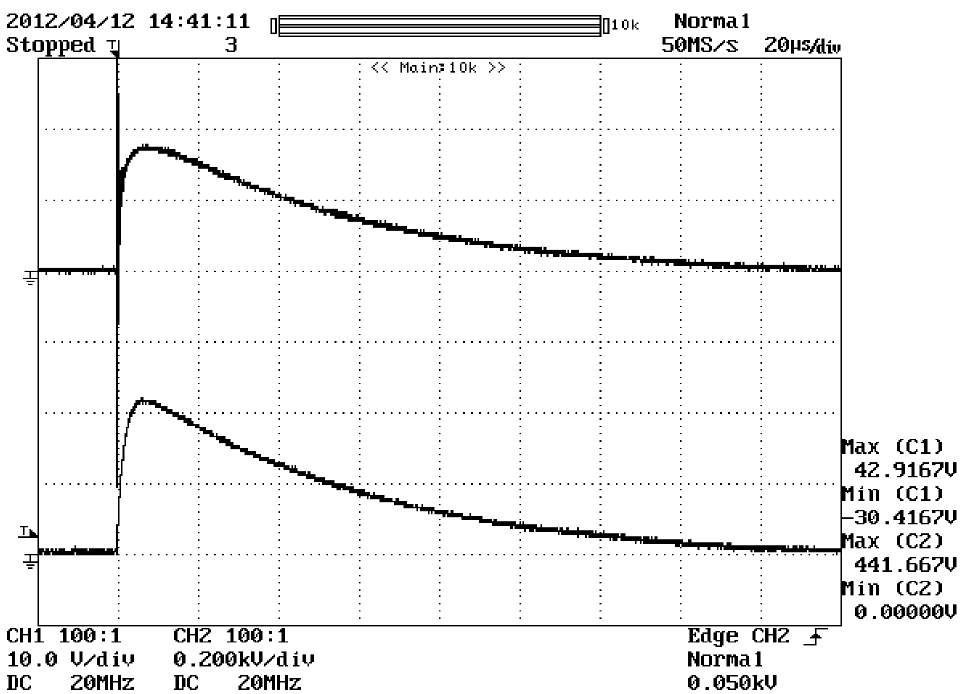


Figure G-52: Al Panel 441 A 0.97(file 047).

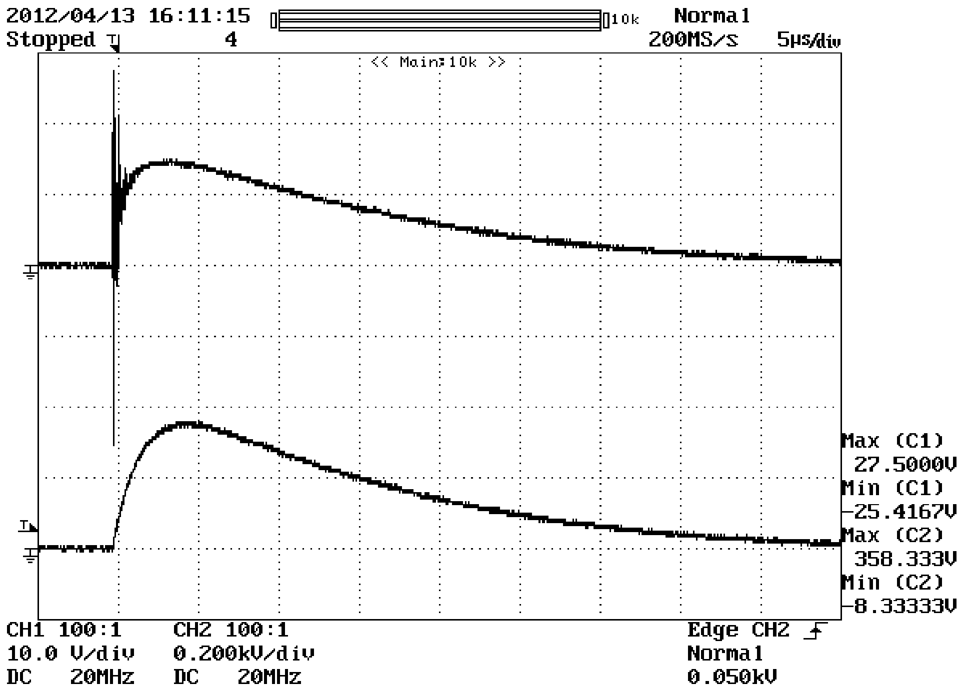


Figure G-53: Carbon Panel WFM 4 & 1 level 3 Pos 358 A and 17 V with 41.4 mΩ resistance (file 090).

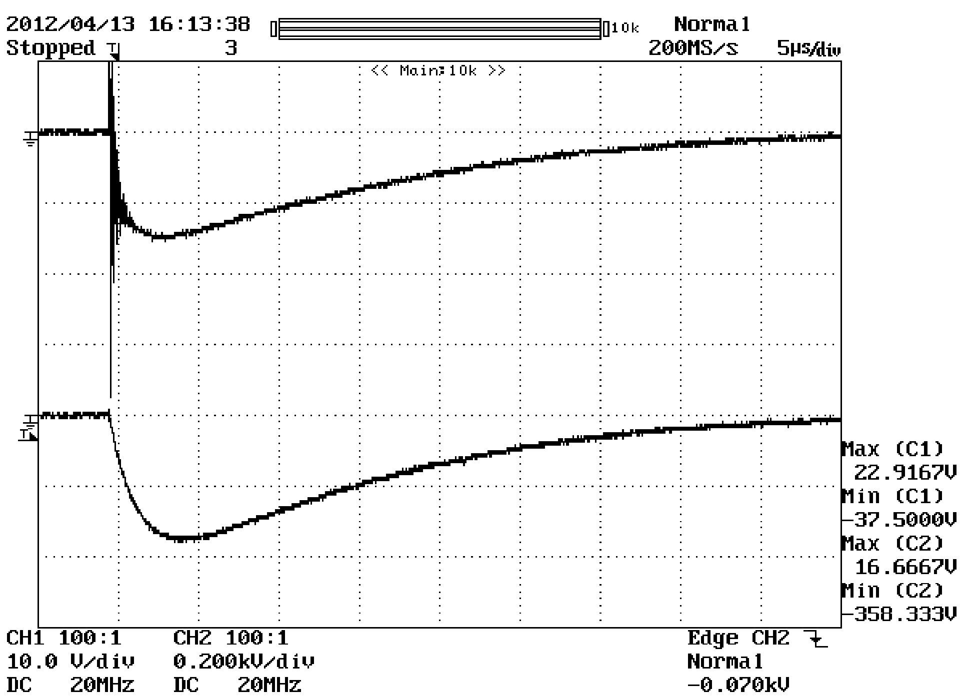


Figure G-54: Carbon Panel WFM 4 & 1 level 3 Neg -358 A and 17 V with 41.4 mΩ resistance (file 091).

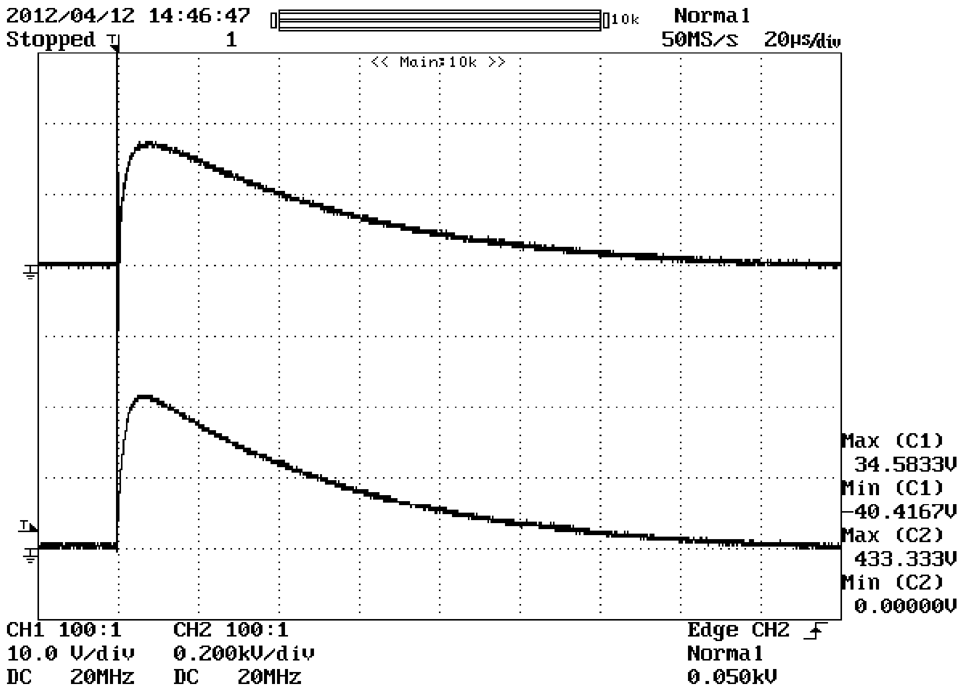


Figure G-55: LS-01 WFM 4 & 1 level 3 Pos 433 A and 17 V with 5.9 mΩ resistance (file 048).

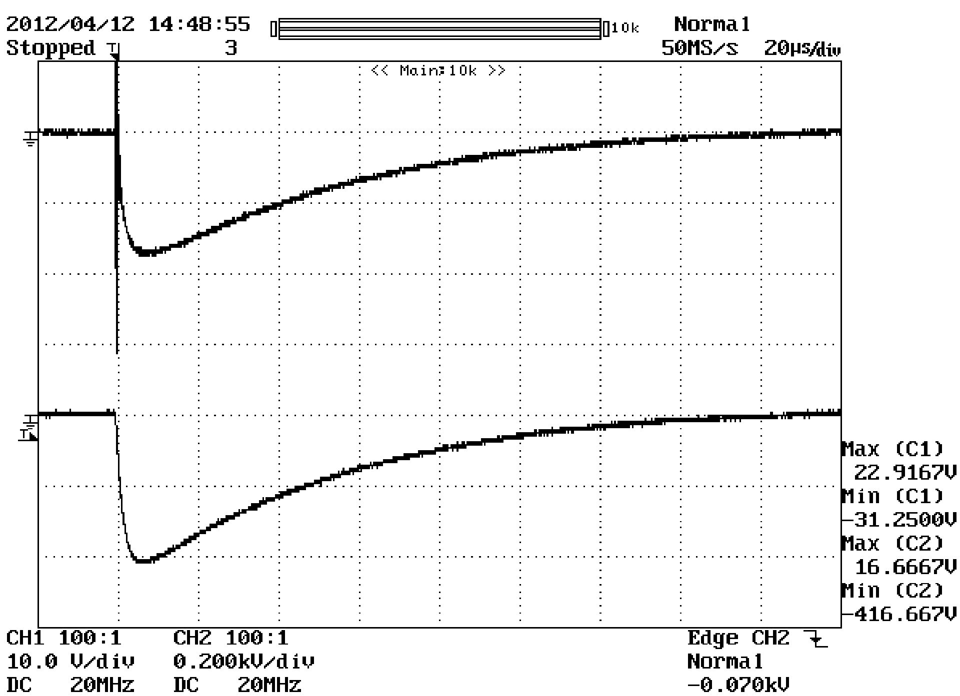


Figure G-56: LS-01 WFM 4 & 1 level 3 Neg -416 A and 17 V with 5.9 mΩ resistance (file 049).

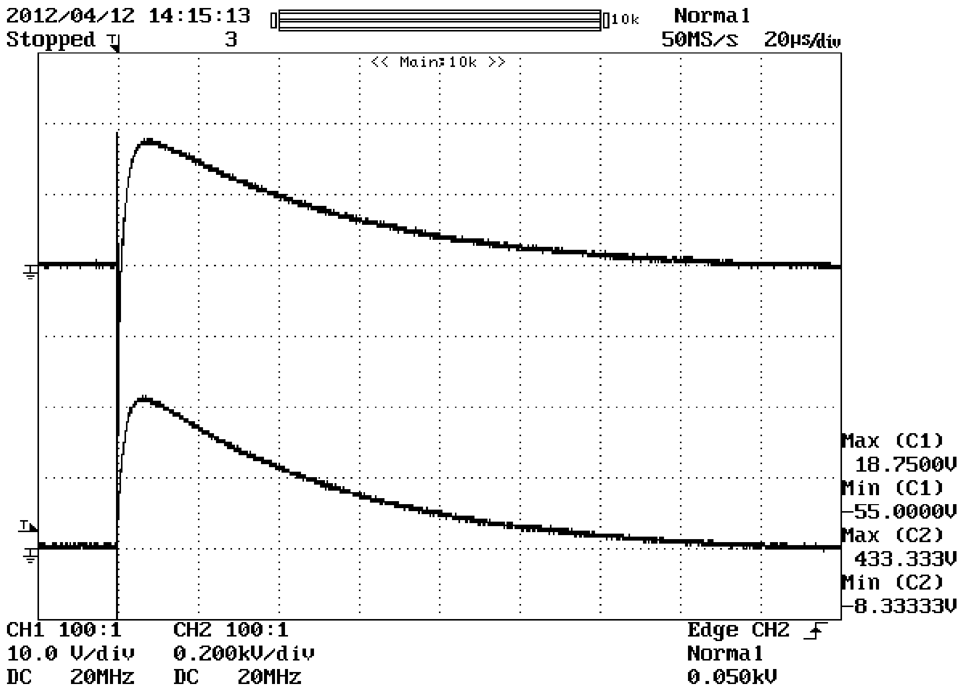


Figure G-57: LS-02 WFM 4 & 1 level 3 Pos 433 A and 17 V with 8.6 mΩ resistance (file 044).

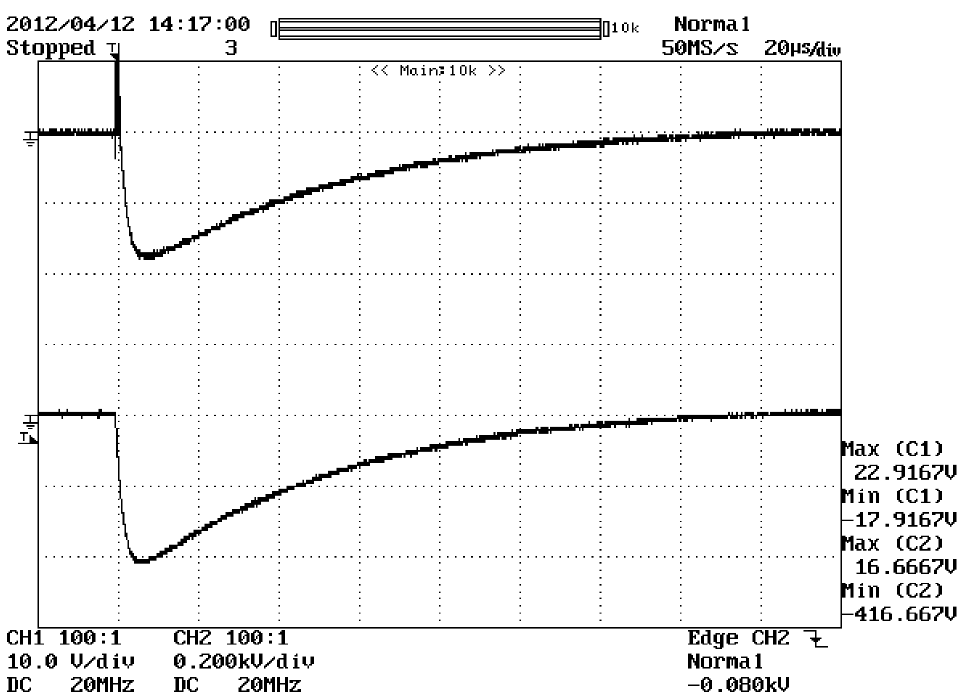


Figure G-58: LS-02 WFM 4 & 1 level 3 Neg -416 A and 17 V with 8.6 mΩ resistance (file 045).

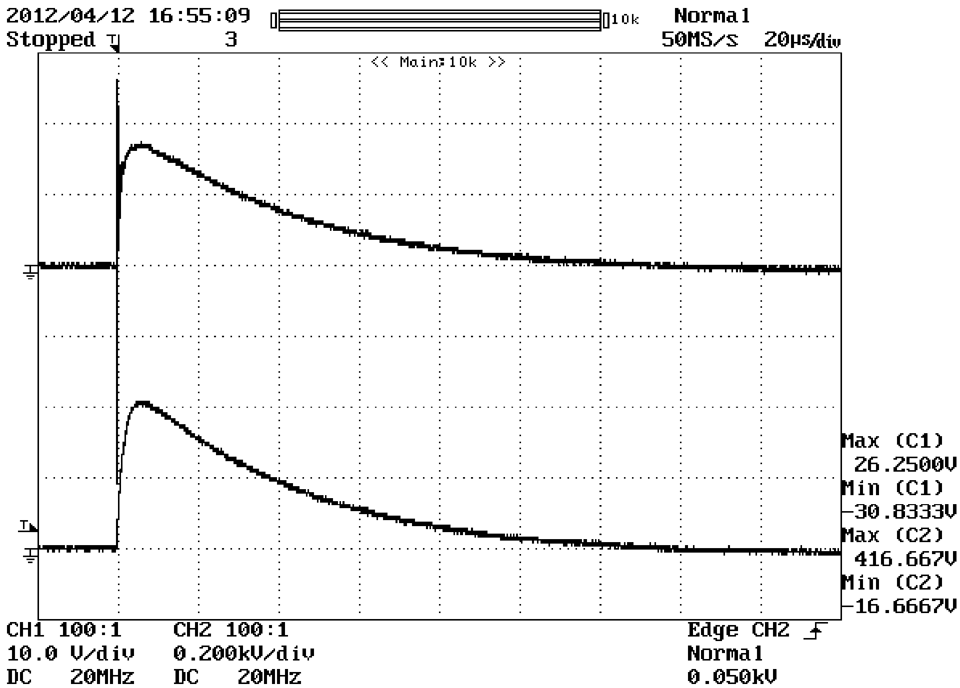
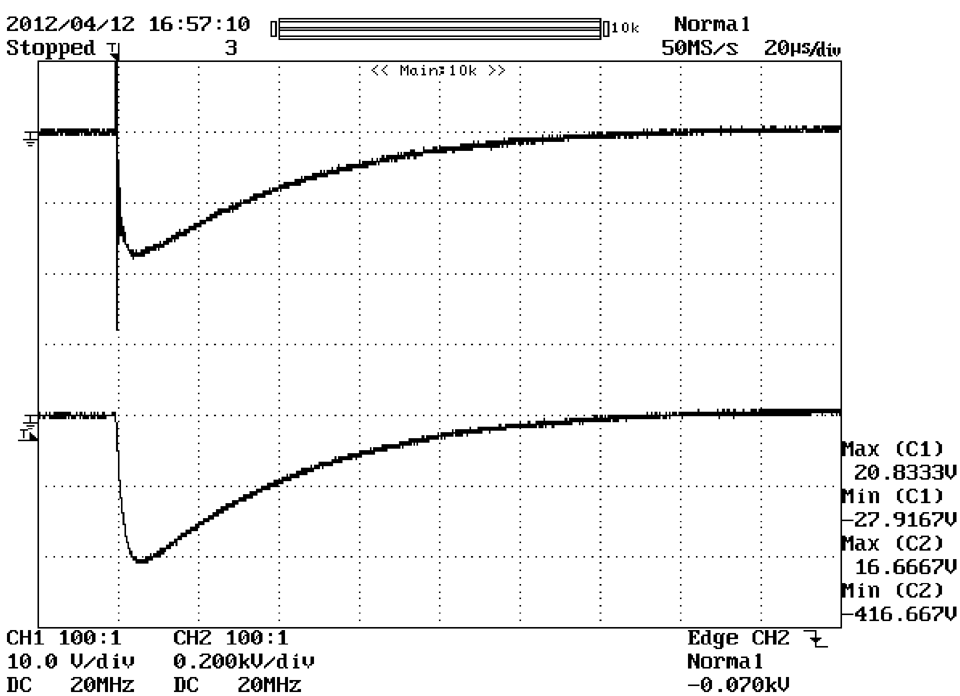


Figure G-59: LS-04 WFM 4 & 1 level 3 Pos 416 A and 17 V with 17.1 mΩ resistance (file 064).



DC 20MHz DC 20MHz 0.050kV).

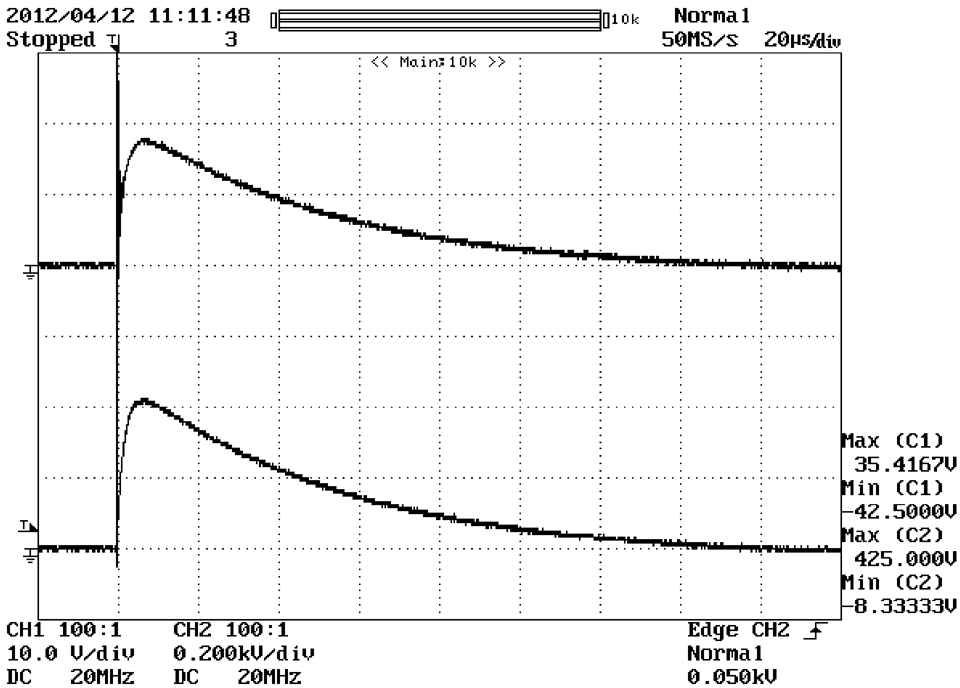


Figure G-61: LS-05 WFM 4 & 1 level 3 Pos 425 A and 17 V with 12.8 mΩ resistance (file 036).

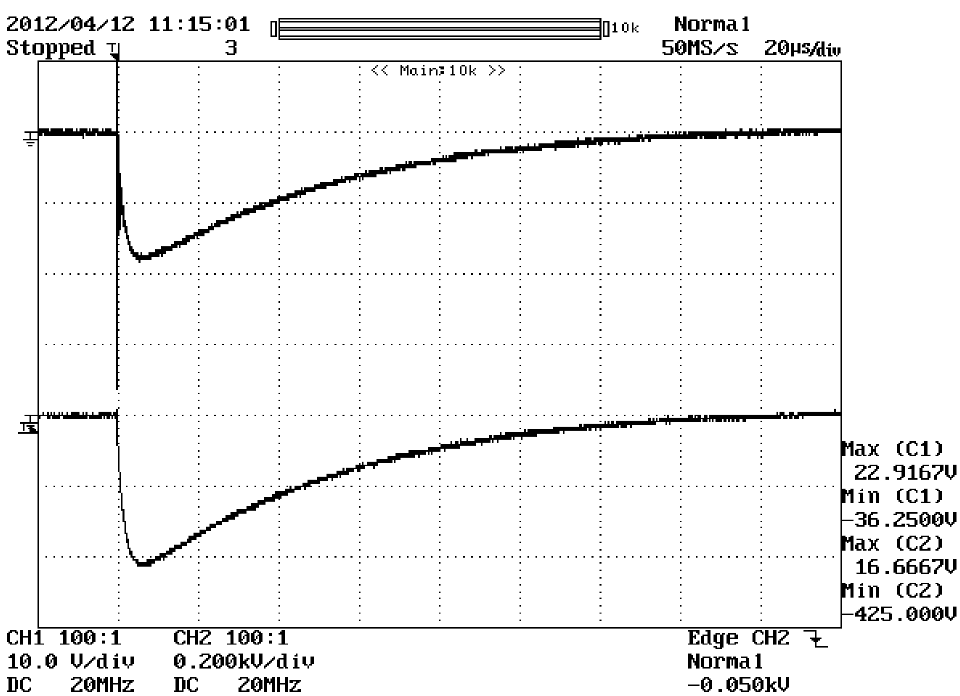


Figure G-62: LS-05 WFM 4 & 1 level 3 Neg -425 A and 17 V with 12.8 mΩ resistance (file 037).

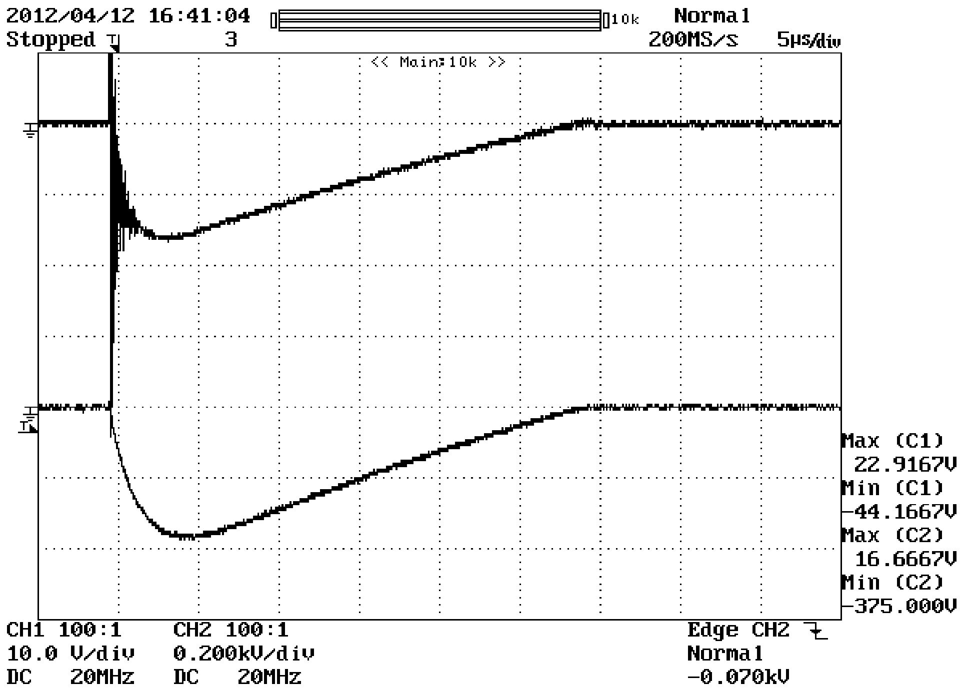


Figure G-63: LS-06 WFM 4 & 1 level 3 Neg -375 A and 17 V with 20.2 mΩ resistance (file 062).

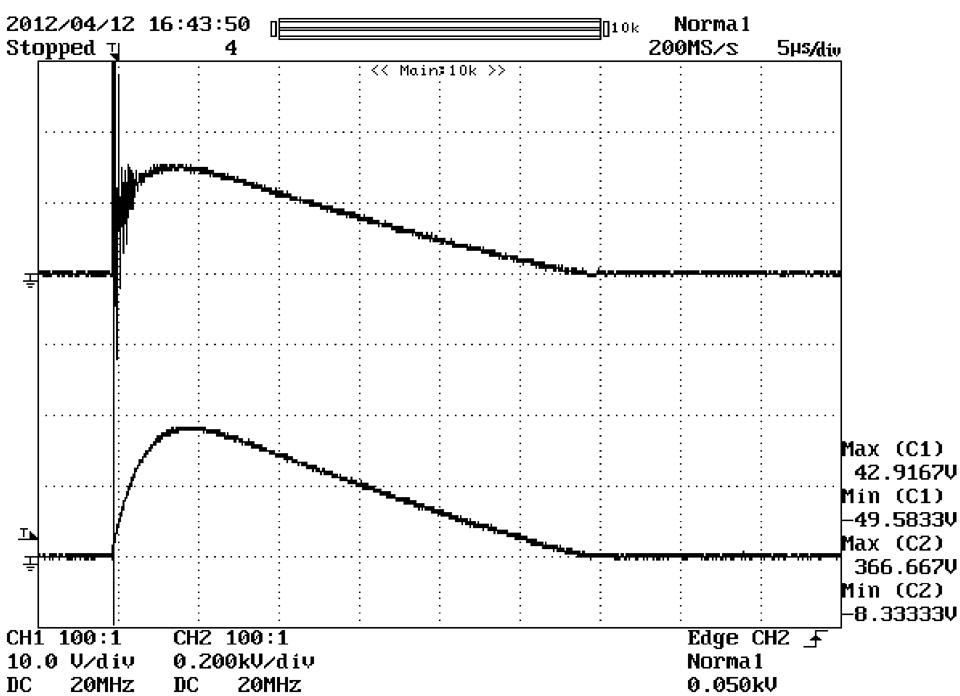


Figure G-64: LS-06 WFM 4 & 1 level 3 Pos 366 A and 17 V with 20.2 mΩ resistance (file 063).

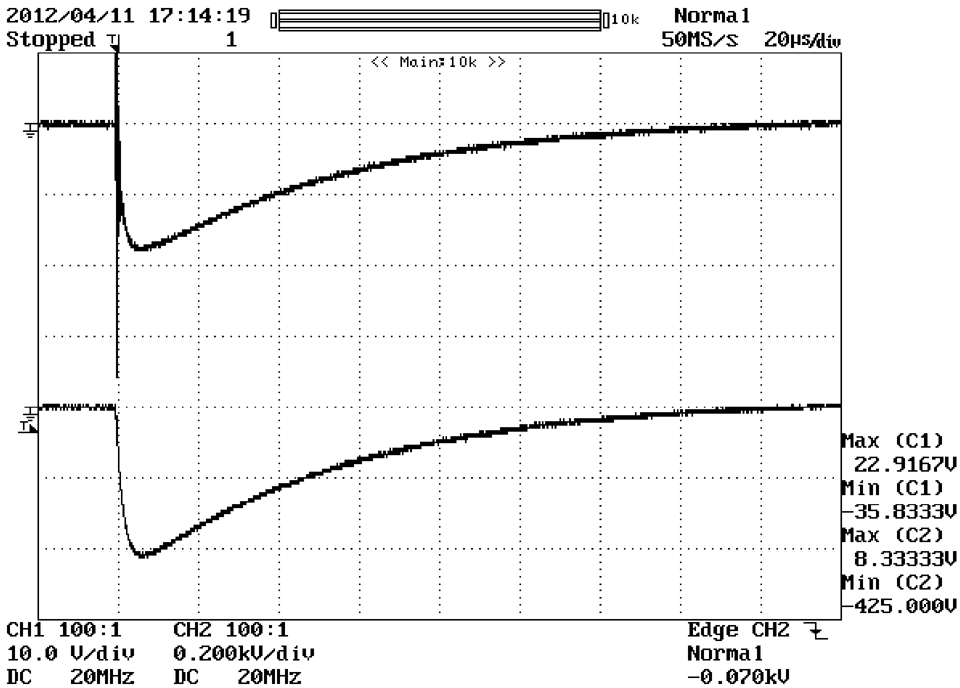


Figure G-65: LS-07 WFM 4 & 1 level 3 Neg -425 A and 17 V with 7.9 mΩ resistance (file 028).

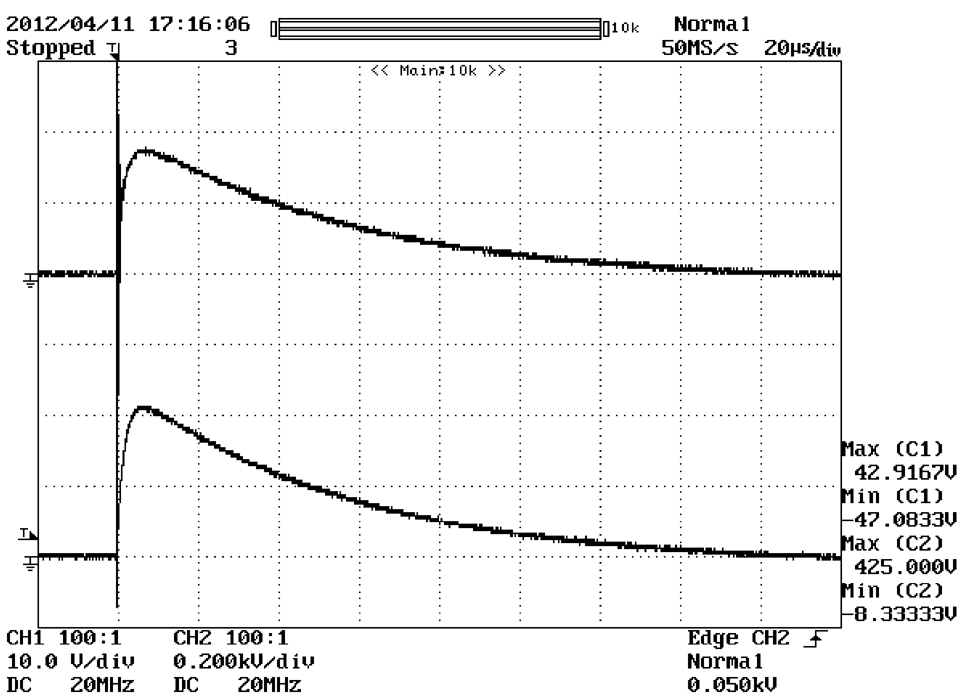


Figure G-66: LS-07 WFM 4 & 1 level 3 Pos 425 A and 17 V with 7.9 mΩ resistance (file 029).

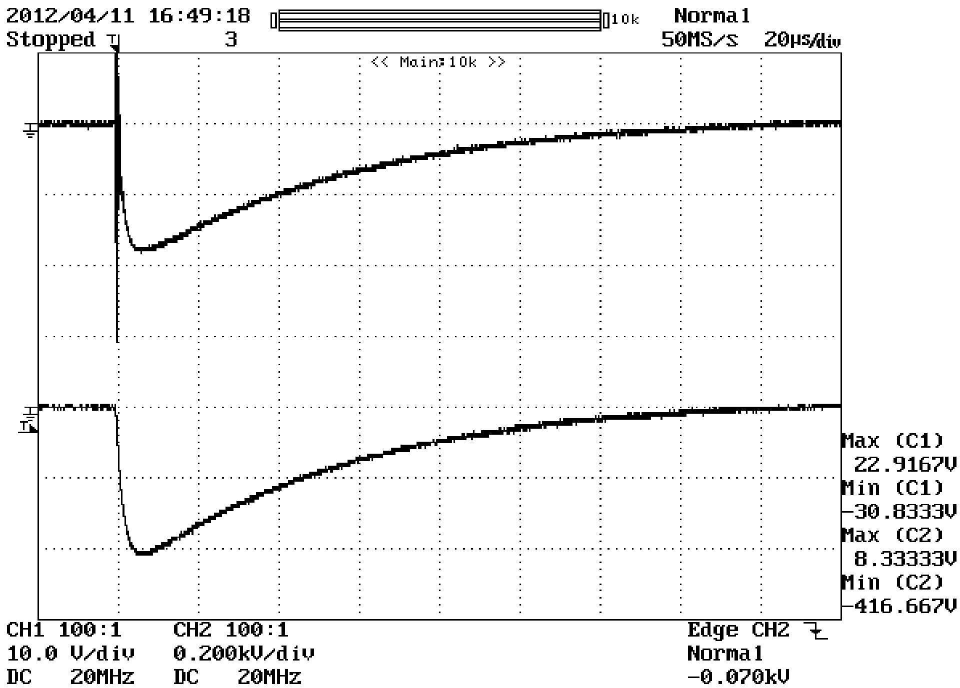


Figure G-67: LS-8 WFM 4 & 1 level 3 Pos Neg -416A and -18 V with 11.2 mΩ resistance (file 024).

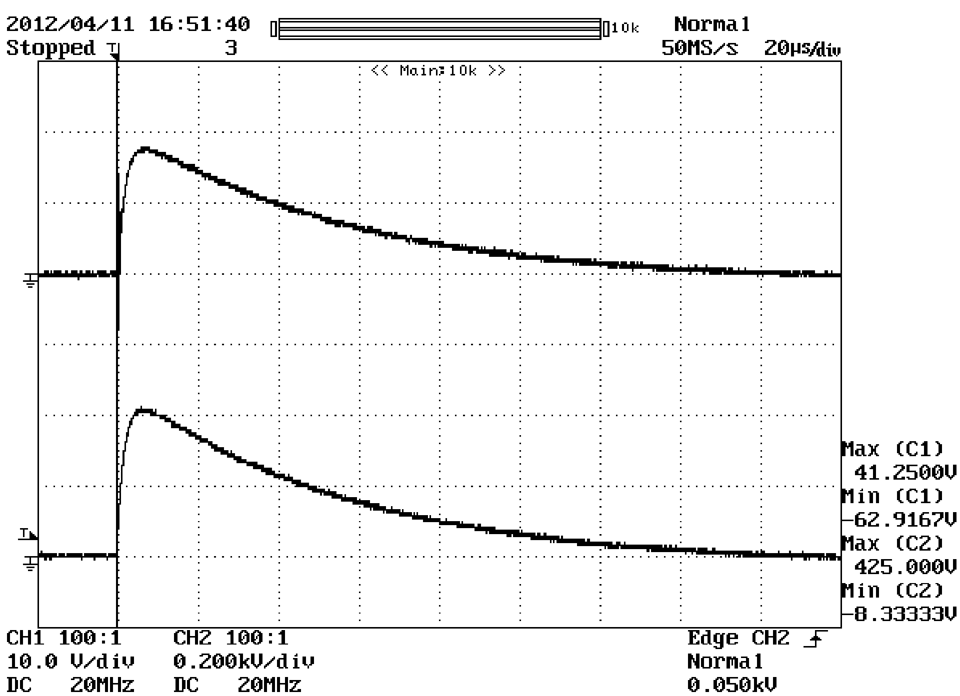


Figure G-68: LS-8 WFM 4 & 1 level 3 Pos 425 A and 18 V with 11.2 mΩ resistance (file 025).

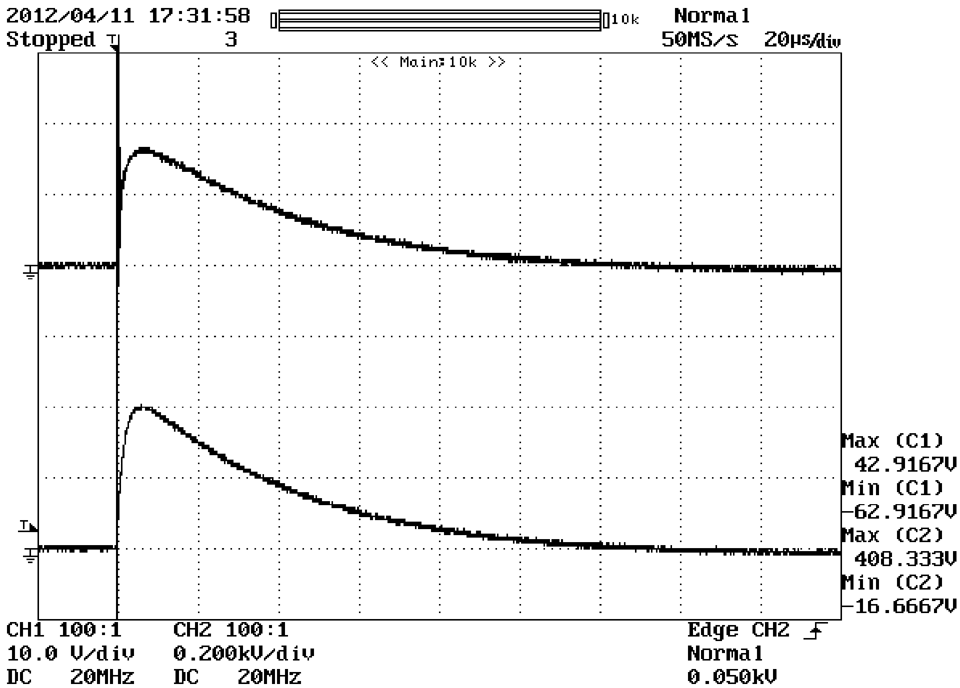


Figure G-69: LS-09 WFM 4 & 1 level 3 Pos 408 A and 17 V with 18.5 mΩ resistance (file 030).

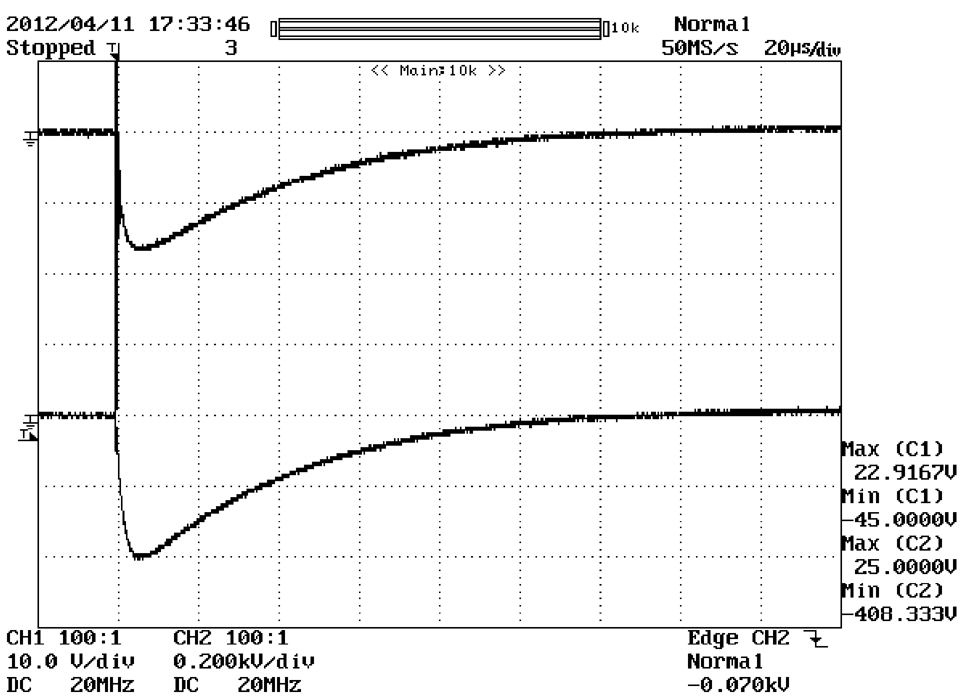


Figure G-70: LS-09 WFM 4 & 1 level 3 Neg -408 A and 17 V with 18.5 mΩ resistance (file 031).

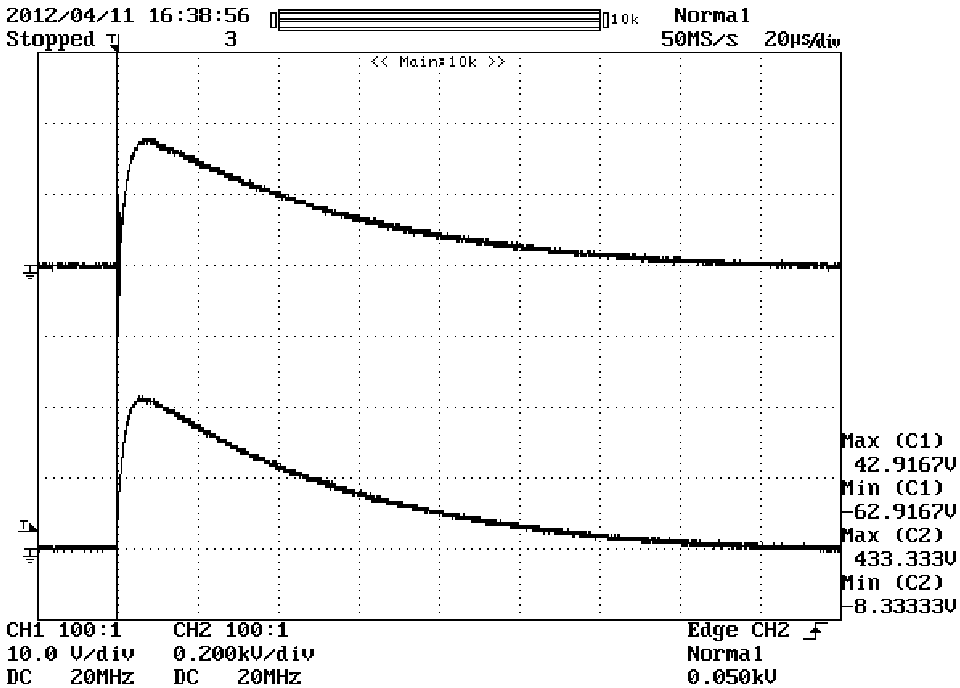


Figure G-71: LS-10 WFM 4 & 1 level 3 Pos 433 A and 18 V with 6.9 mΩ resistance (file 022).

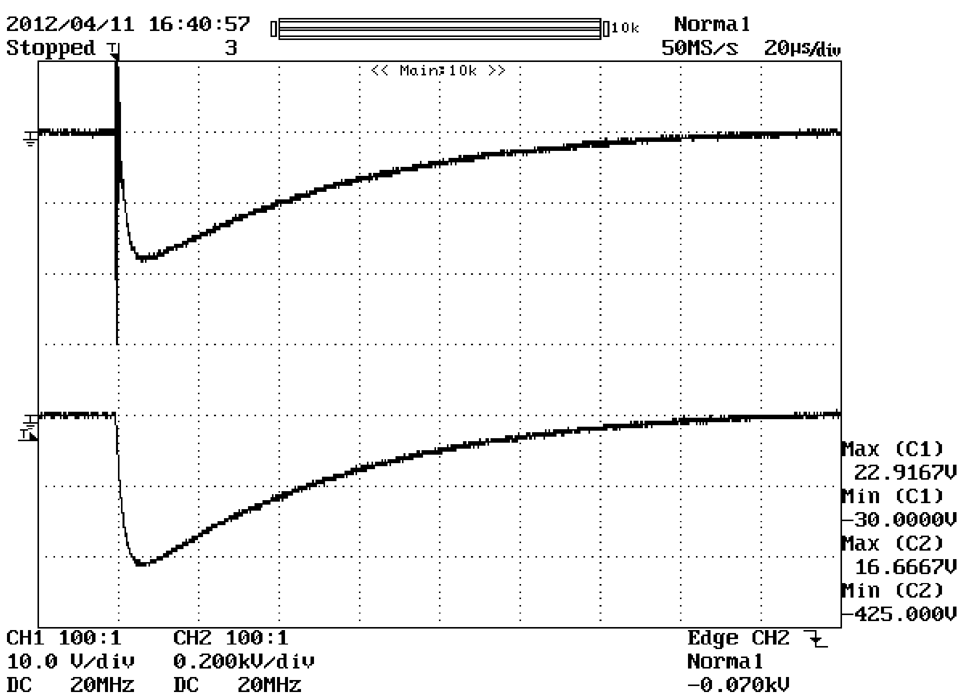


Figure G-72: LS-10 WFM 4 & 1 level 3 Neg -425 A and -18 V with 6.9 mΩ resistance (file 023).

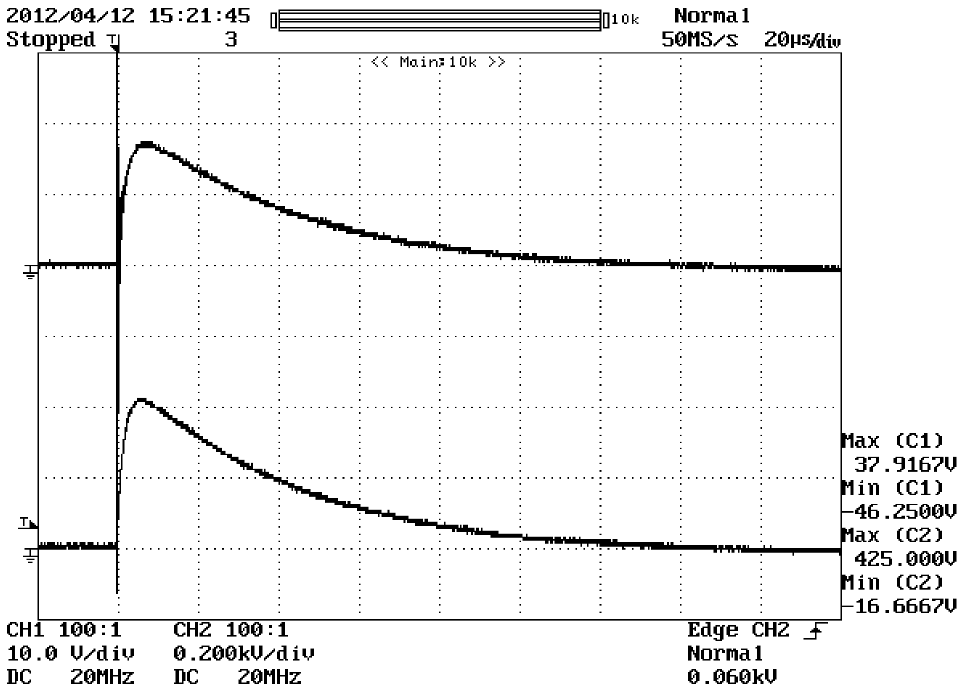


Figure G-73: LS-11 WFM 4 & 1 level 3 Pos 425 A and 17 V with 21.1 mΩ resistance (file 052).

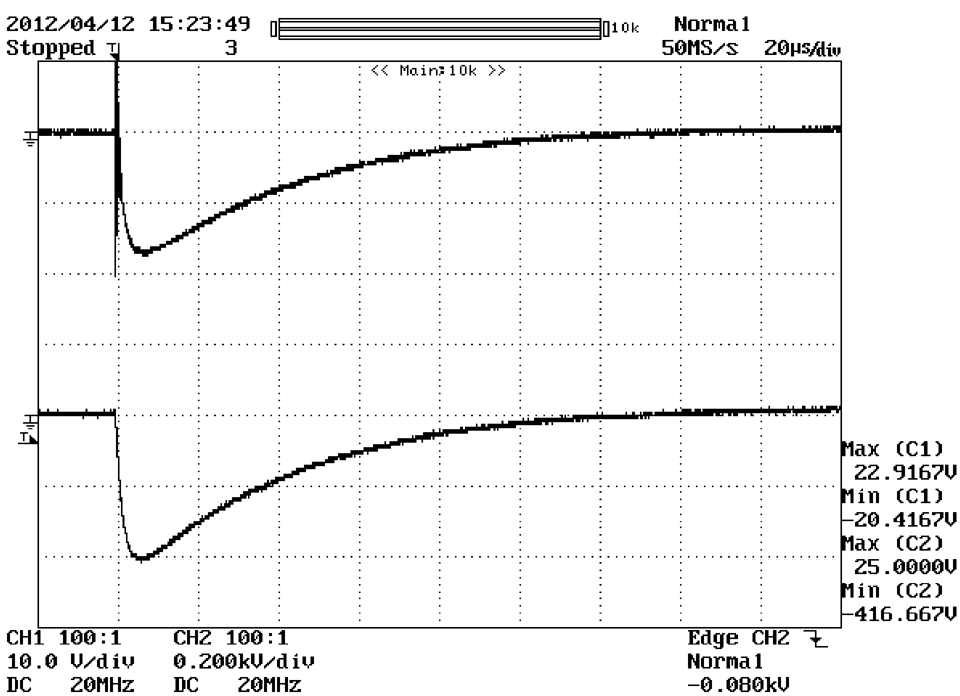


Figure G-74: LS-11 WFM 4 & 1 level 3 Neg -416 A and 17 V with 21.1 mΩ resistance (file 053).

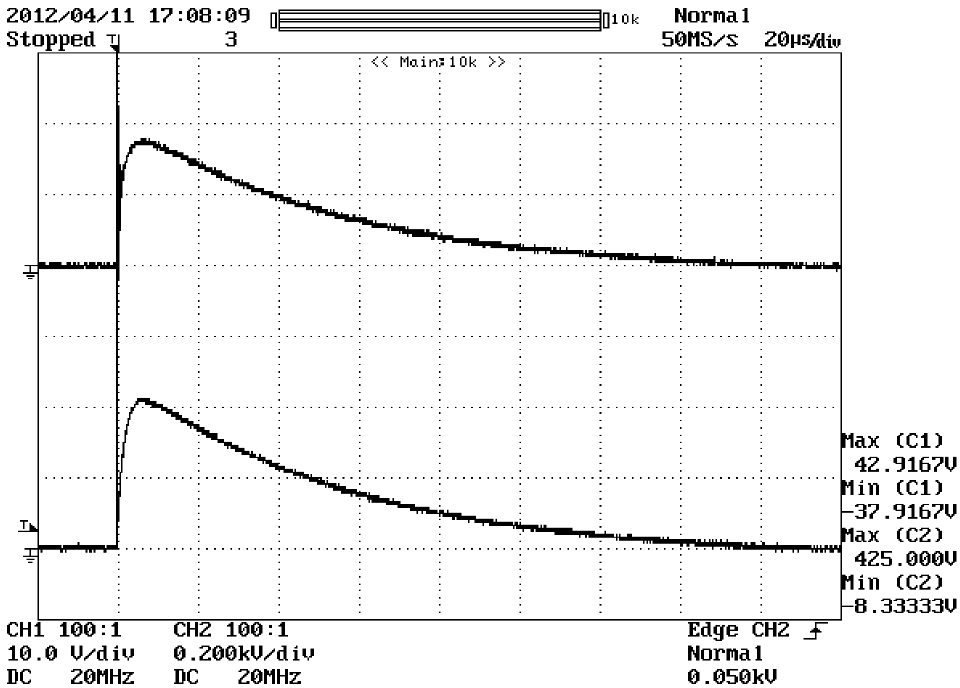


Figure G-75: LS-12 WFM 4 & 1 level 3 Pos 425 A and 17 V with 7.7 mΩ resistance (file 026).

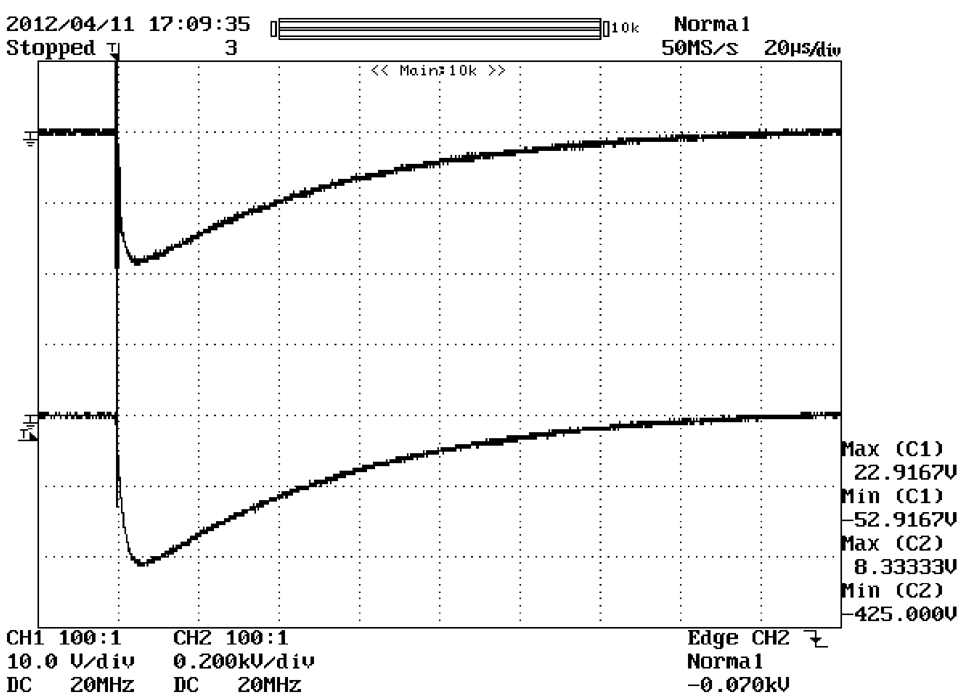


Figure G-76: LS-12 WFM 4 & 1 level 3 Neg -425 A and 17 V with 7.7 mΩ resistance (file 027).

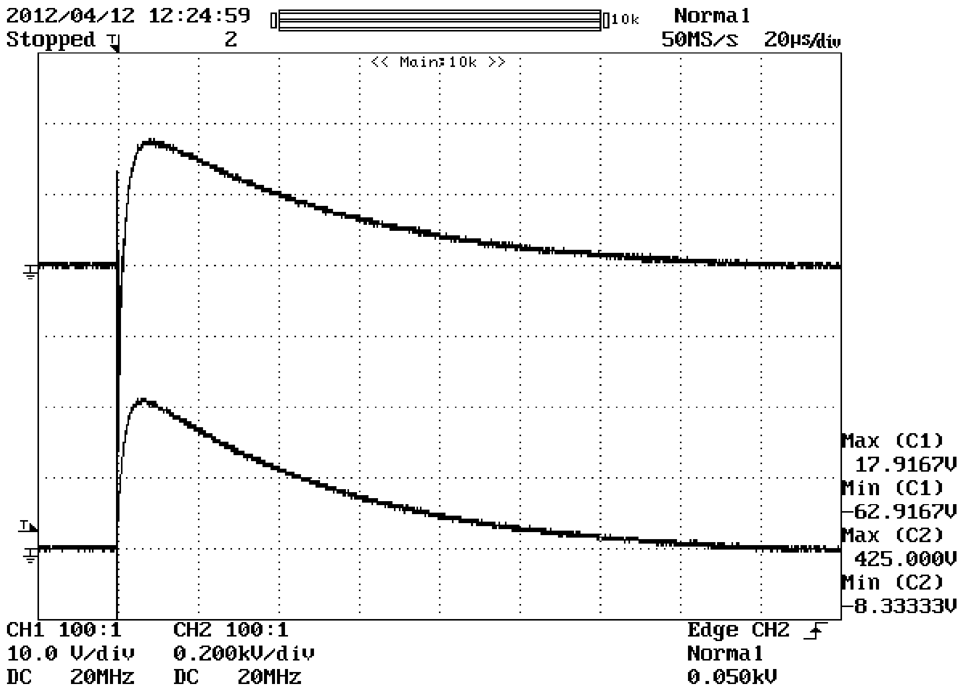


Figure G-77: LS-13 WFM 4 & 1 level 3 Pos 425 A and 17 V with 9.8 mΩ resistance (file 040).

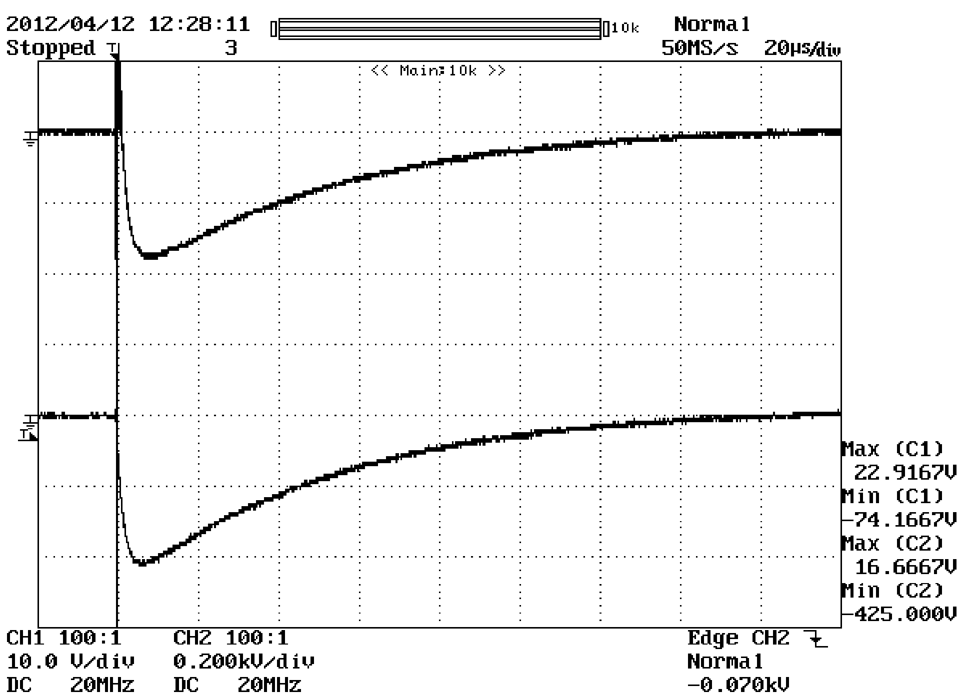


Figure G-78: LS-13 WFM 4 & 1 level 3 Neg -425 A and 17 V with 9.8 mΩ resistance (file 041).

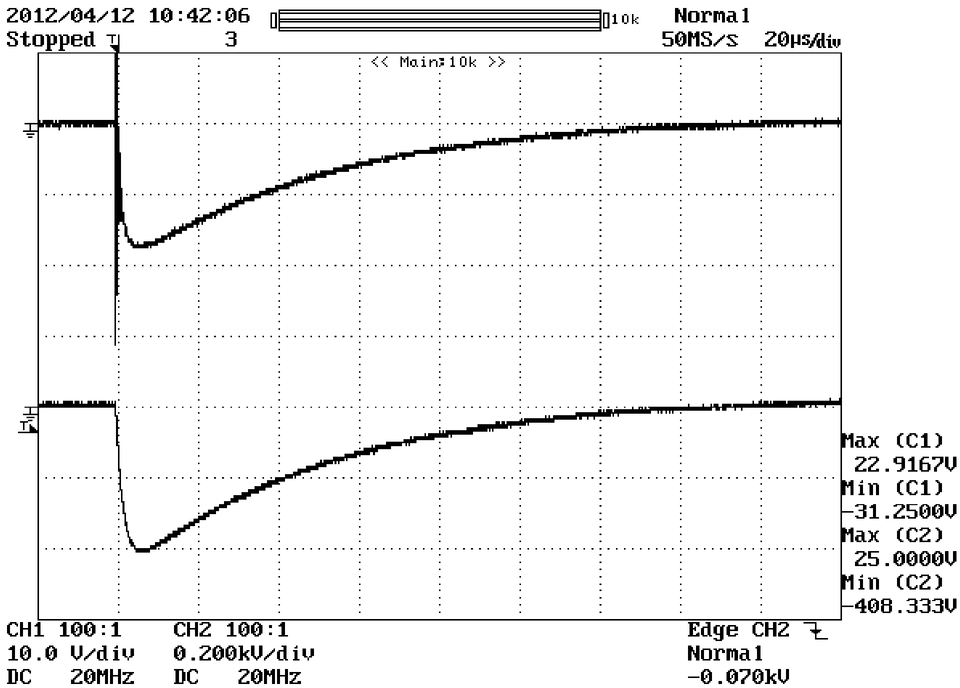


Figure G-79: LS-14 WFM 4 & 1 level 3 Neg -408 A and 17 V with 7.9 mΩ resistance (file 032).

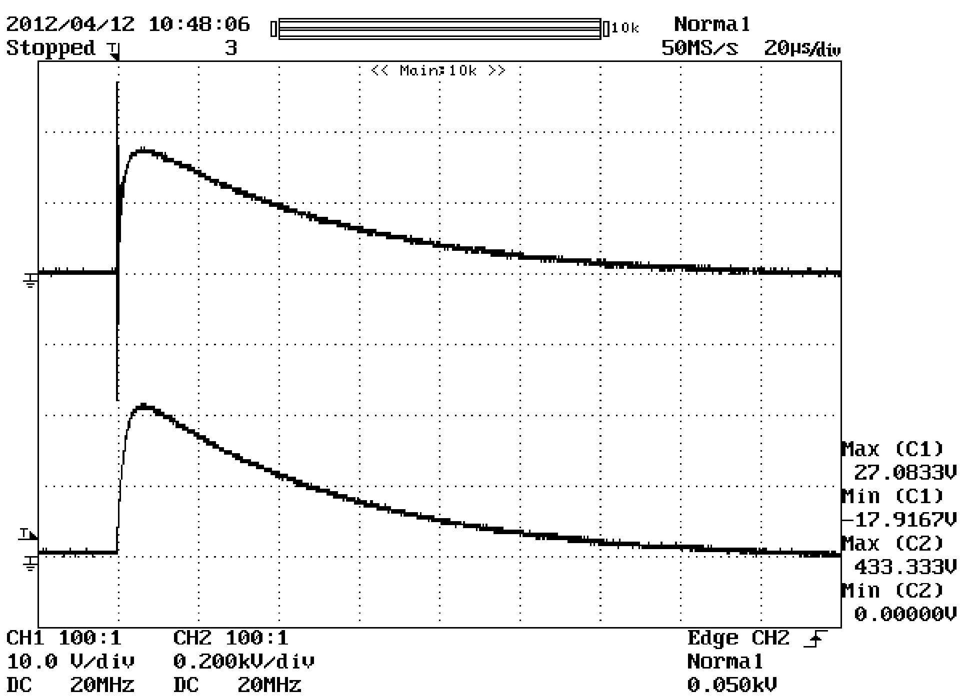


Figure G-80: LS-14 WFM 4 & 1 level 3 Pos 433 A and 17 V with 7.9 mΩ resistance (file 033).

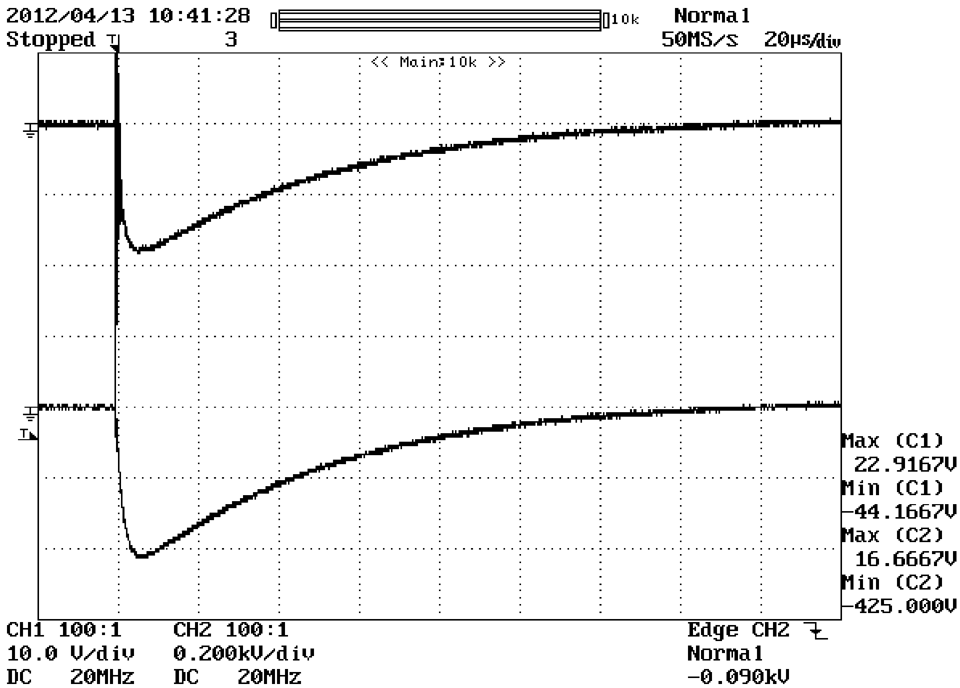


Figure G-81: LS-15 WFM 4 & 1 level 3 Neg -425 A and 17 V with 35.6 mΩ resistance (file 076).

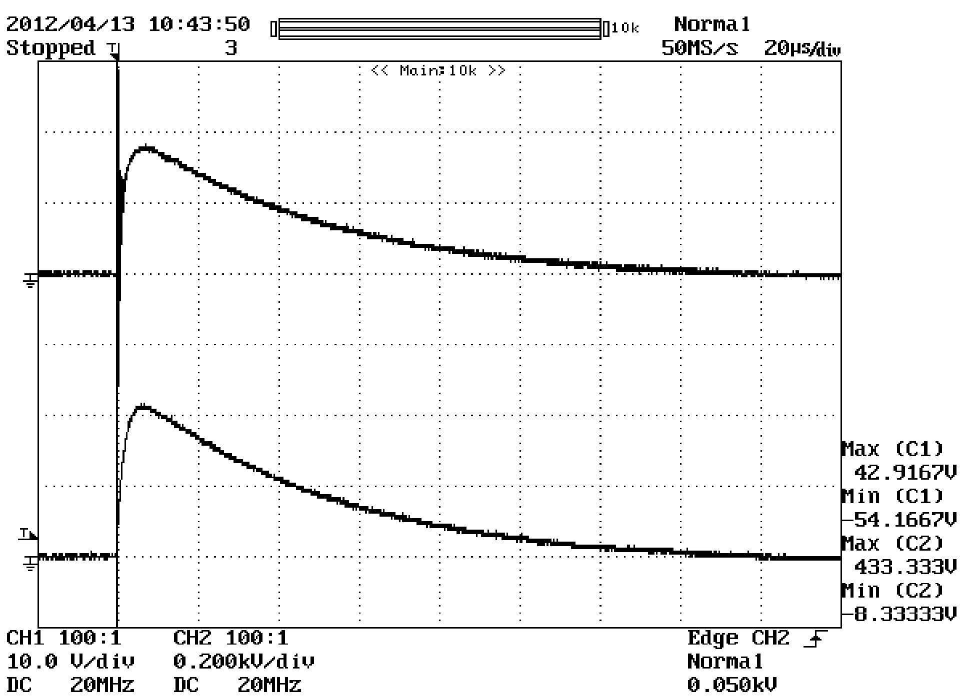


Figure G-82: LS-15 WFM 4 & 1 level 3 Neg 433 A and 17 V with 35.6 mΩ resistance (file 077).

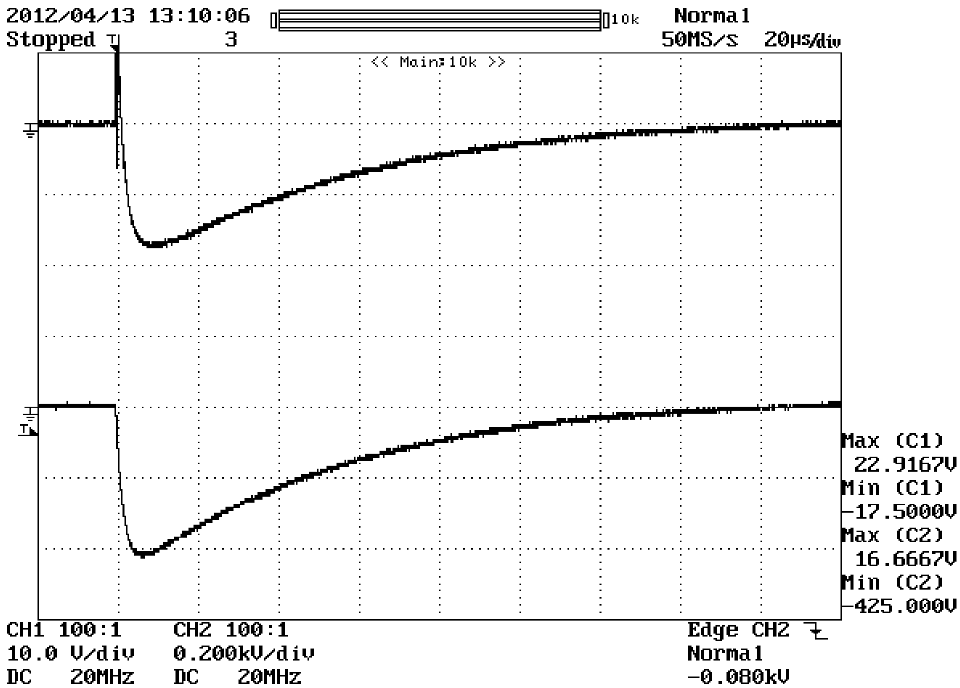


Figure G-83: LS-16 WFM 4 & 1 level 3 Neg -425 A and 17 V with 8.3 mΩ resistance (file 080).

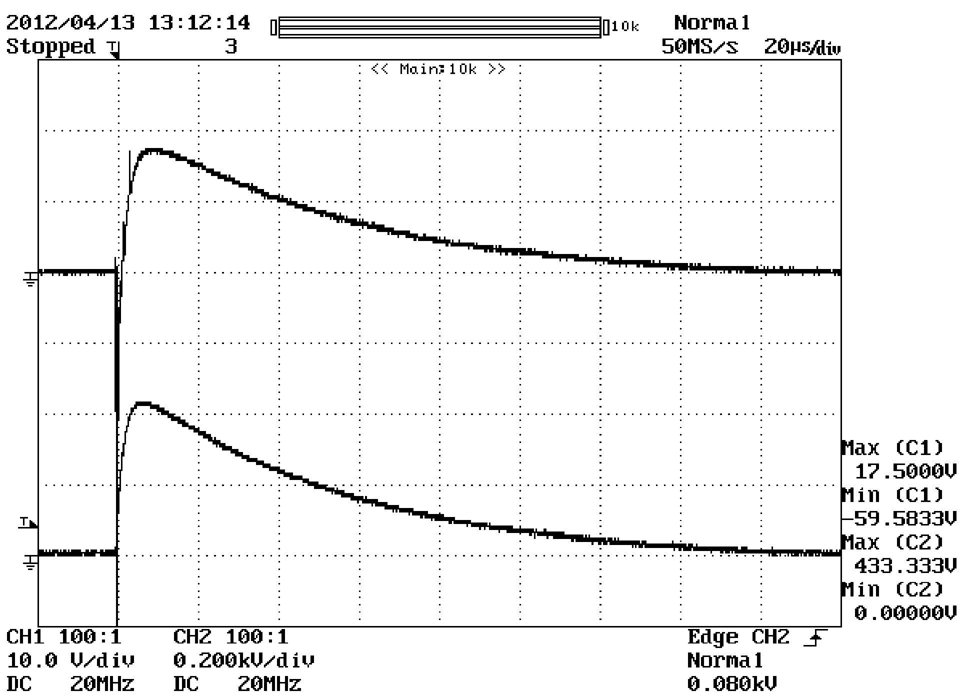


Figure G-84: LS-16 WFM 4 & 1 level 3 Pos 433 A and 17 V with 8.3 mΩ resistance (file 081).

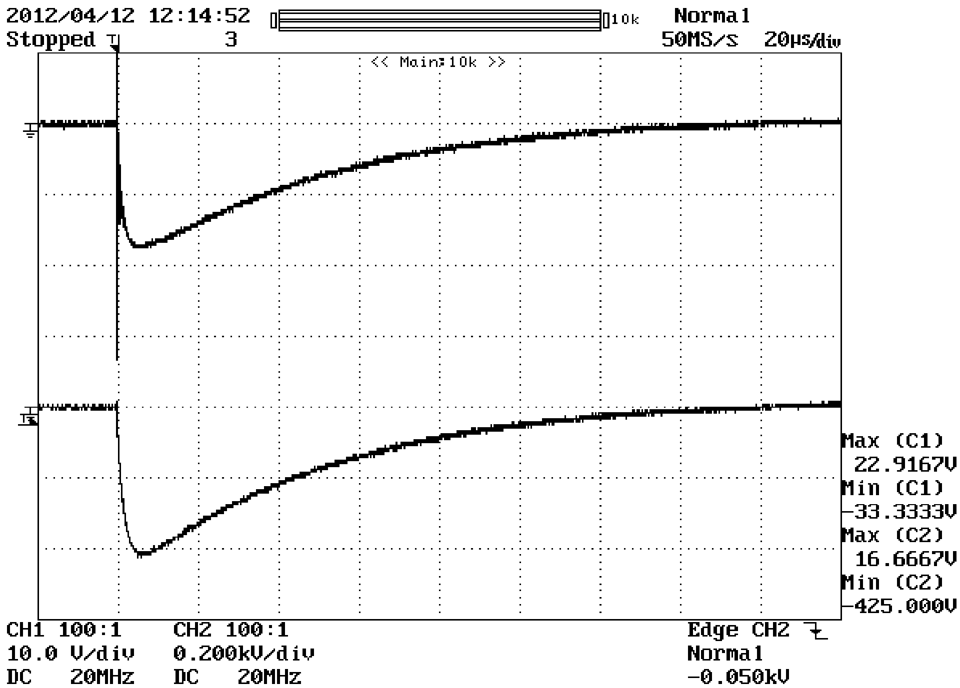


Figure G-85: LS-18 WFM 4 & 1 level 3 Neg -425 A and 17 V with 22.6 mΩ resistance (file 038).

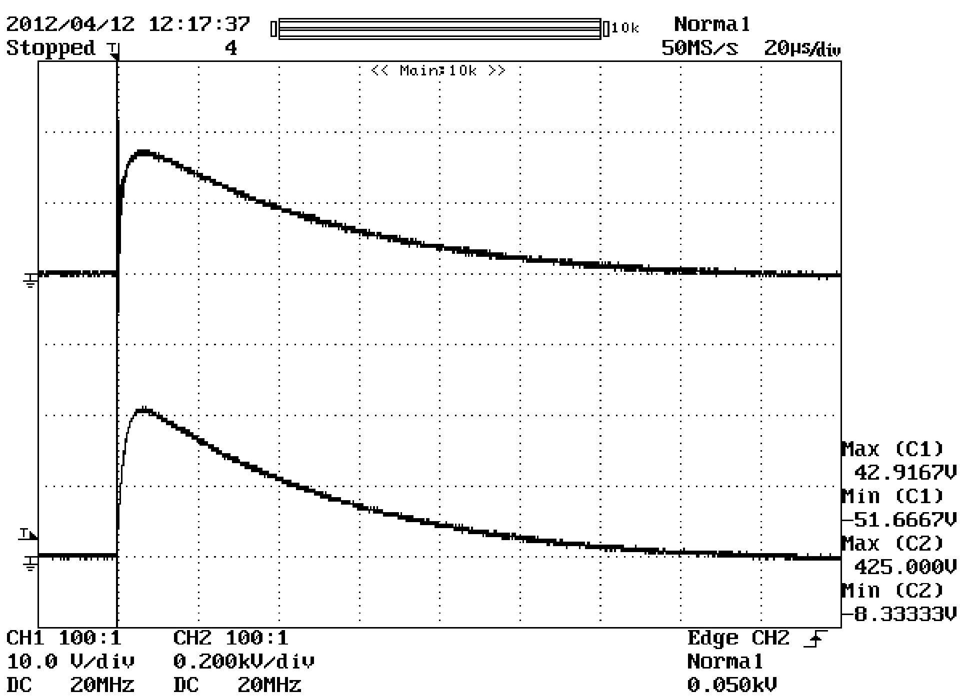


Figure G-86: LS-18 WFM 4 & 1 level 3 Pos 425 A and 17 V with 22.6 mΩ resistance (file 039).

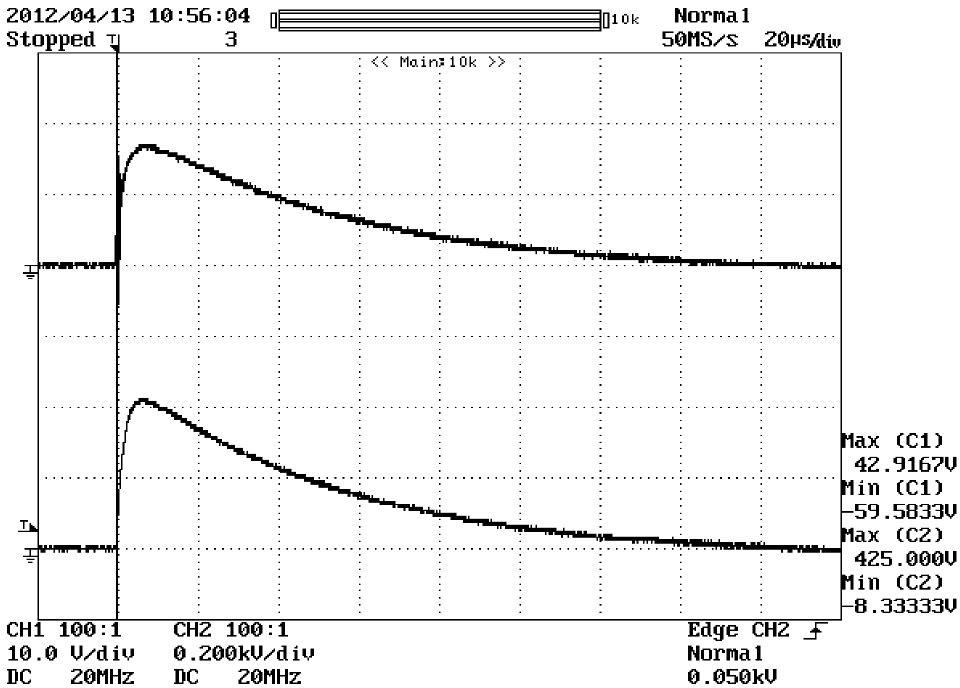


Figure G-87: LS-19 WFM 4 & 1 level 3 Pos 425 A and 17 V with 8.1 mΩ resistance (file 078).

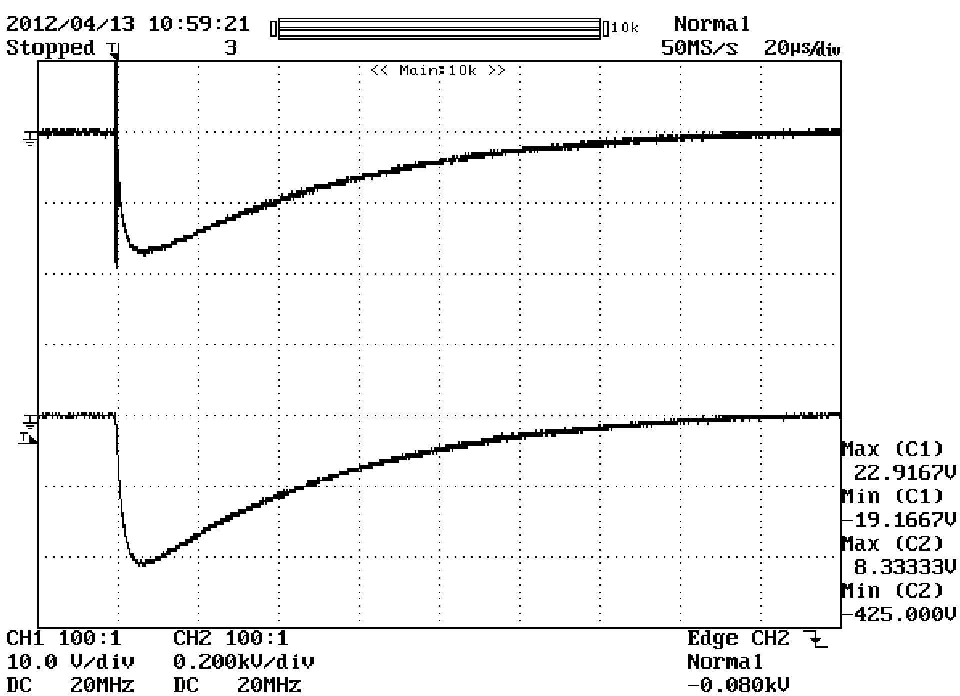


Figure G-88: LS-19 WFM 4 & 1 level 3 Neg -425 A and 17 V with 8.1 mΩ resistance (file 079).

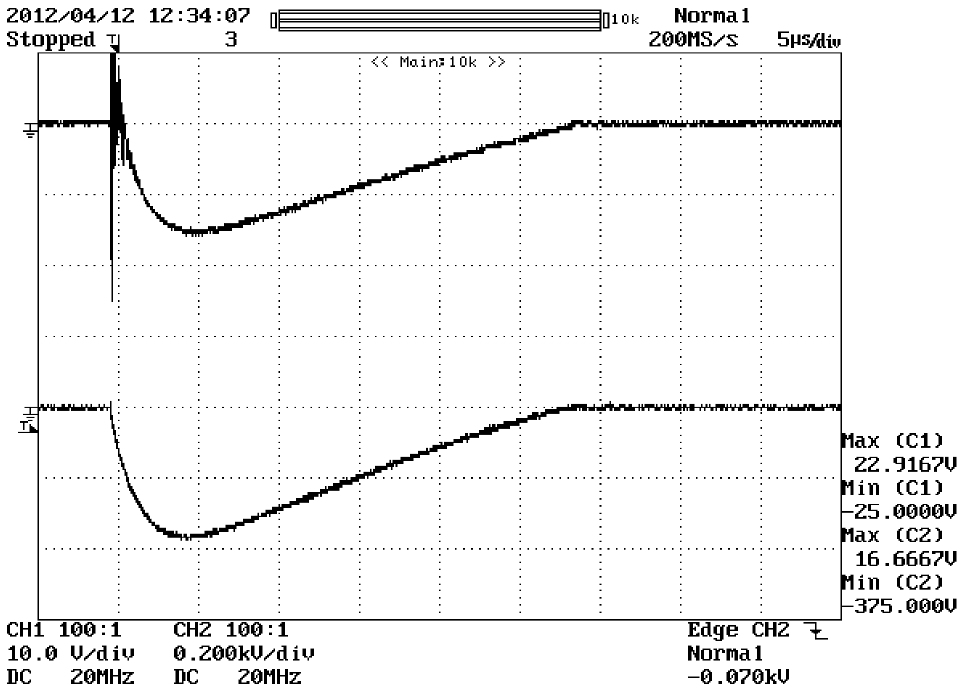


Figure G-89: LS-20 WFM 4 & 1 level 3 Neg -375 A and 17 V with 37.5 mΩ resistance (file 042).

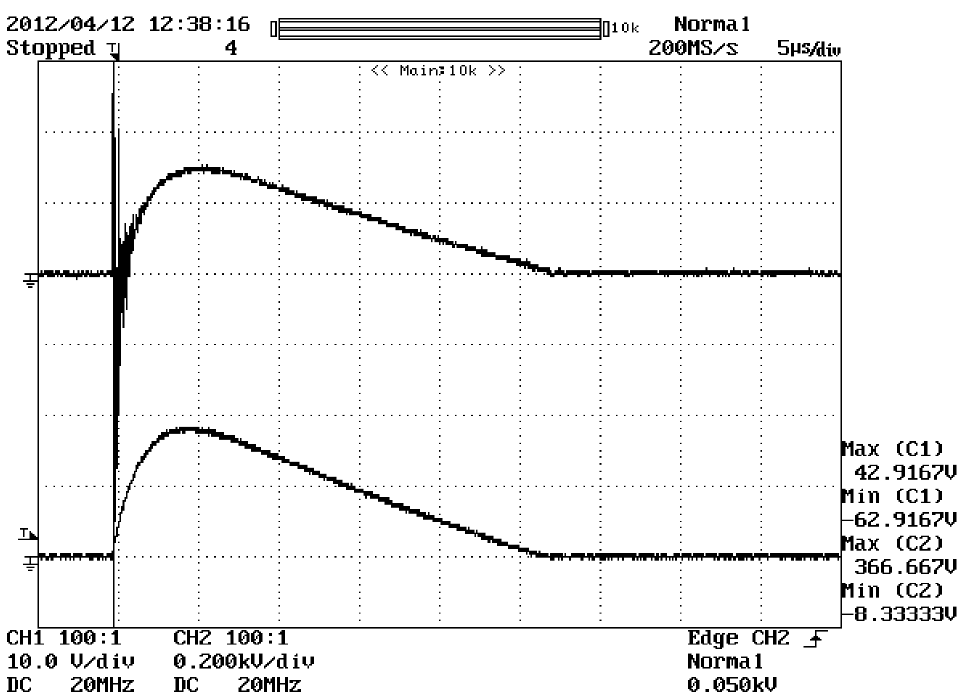


Figure G-90: LS-20 WFM 4 & 1 level 3 Pos 366 A and 17 V with 37.5 mΩ resistance (file 043).

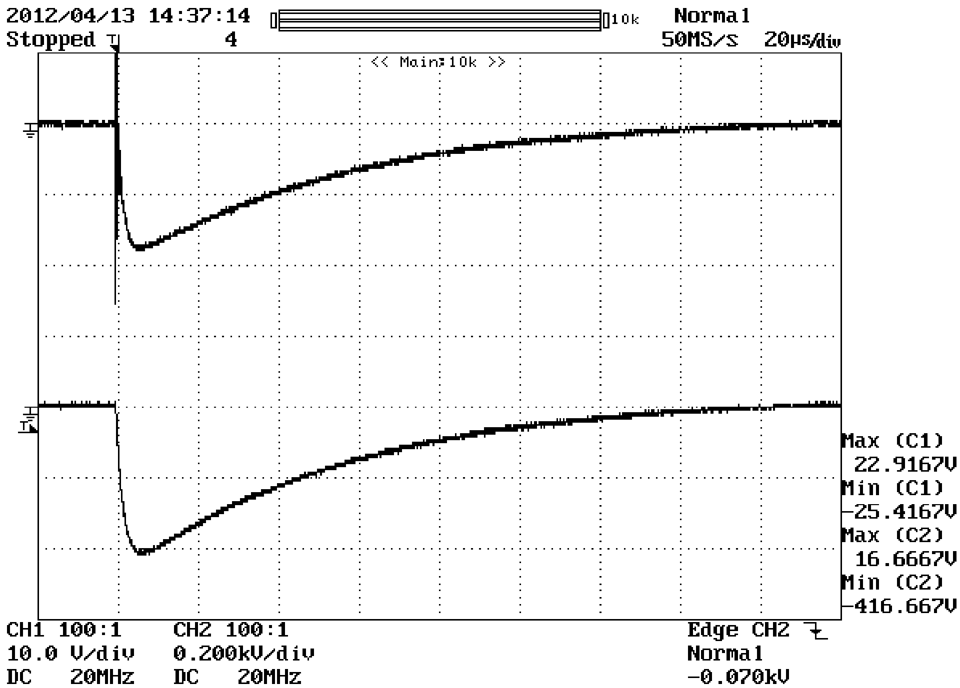


Figure G-91: LS-21 WFM 4 & 1 level 3 Neg -416 A and 17 V with 6.4 mΩ resistance (file 084).

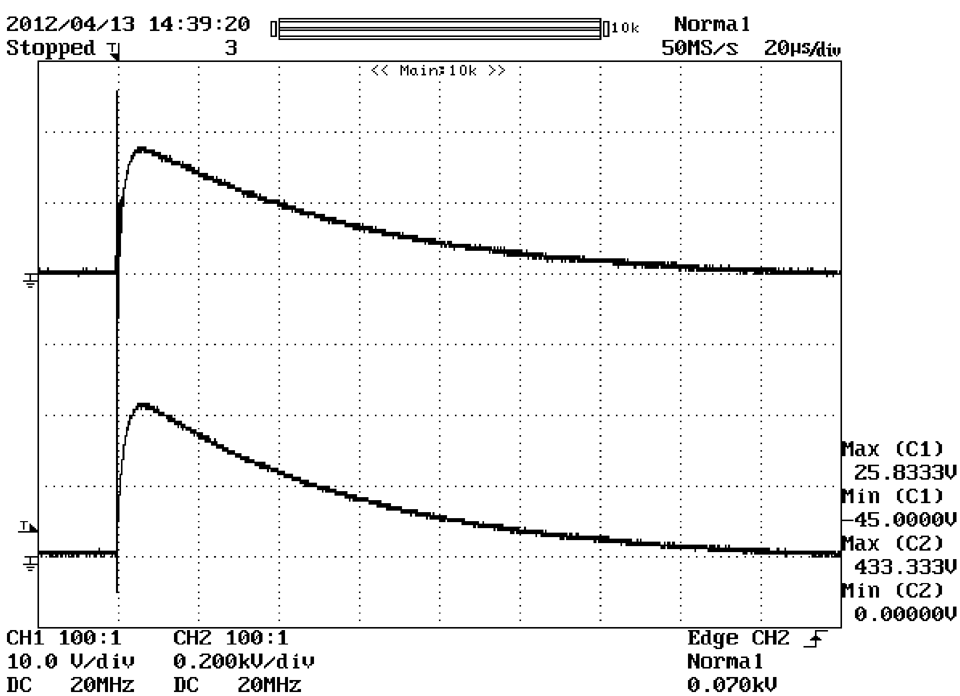


Figure G-92: LS-21 WFM 4 & 1 level 3 Pos 433 A and 17 V with 6.4 mΩ resistance (file 085).

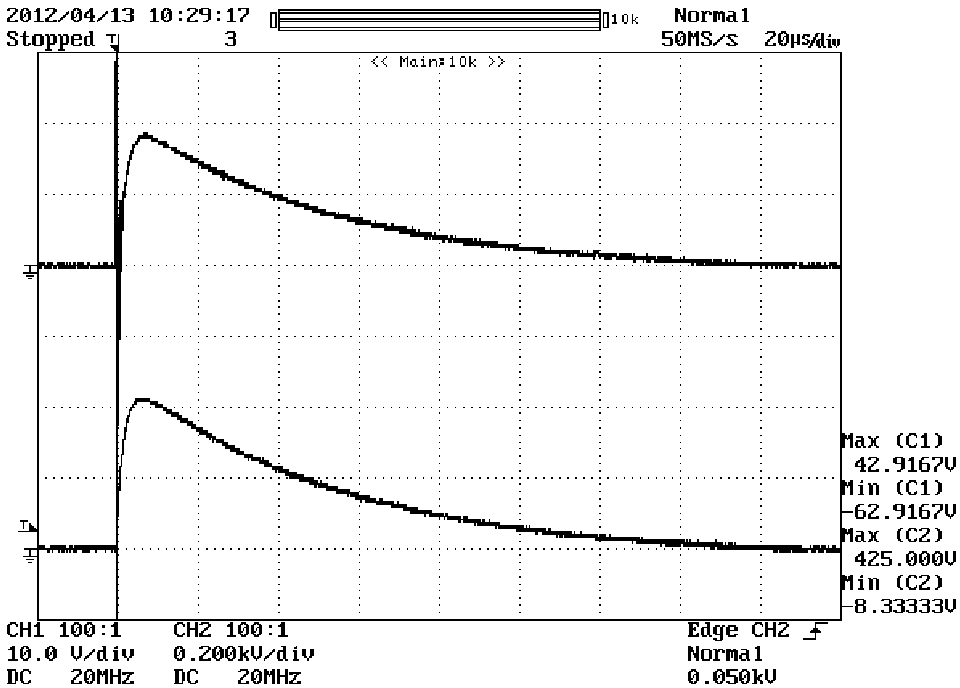


Figure G-93: LS-22 WFM 4 & 1 level 3 Pos 425 A and 17 V with 15.0 mΩ resistance (file 074).

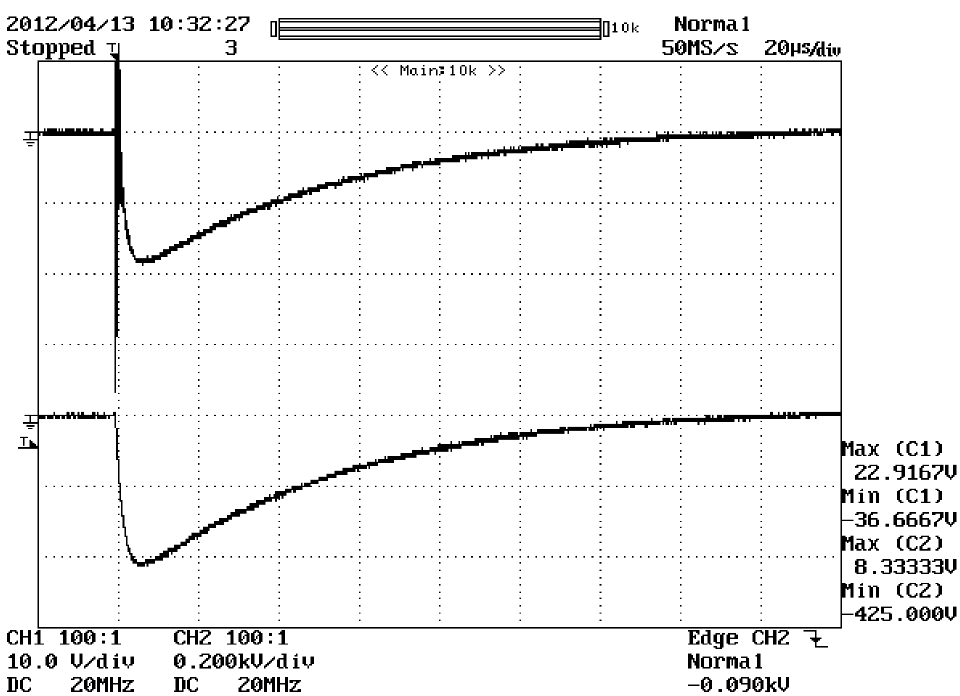


Figure G-94: LS-22 WFM 4 & 1 level 3 Neg -425 A and 17 V with 15.0 mΩ resistance (file 075).

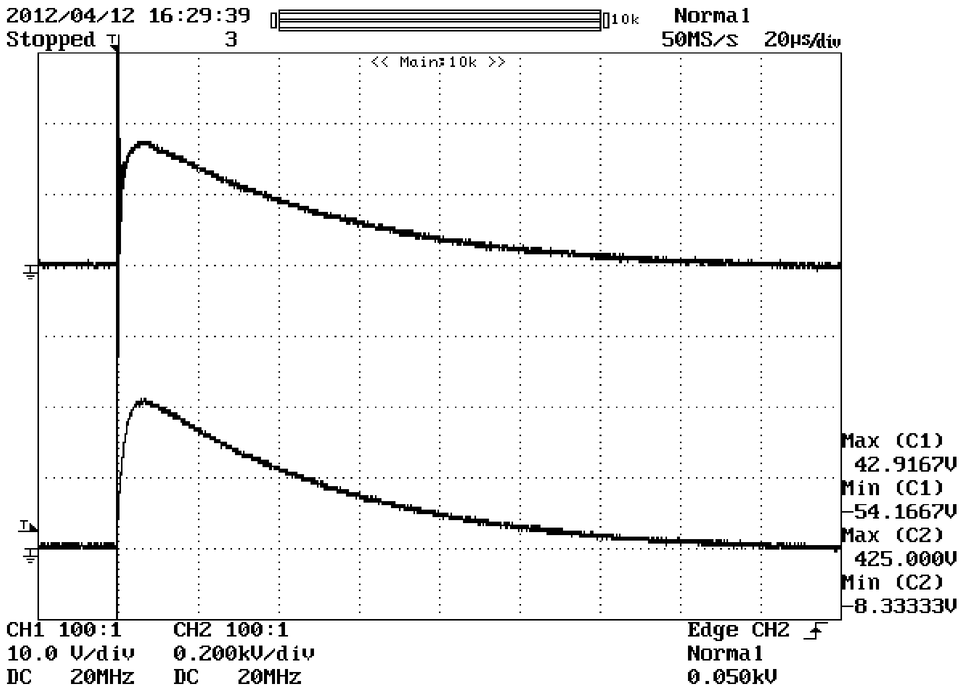


Figure G-95: LS-23 WFM 4 & 1 level 3 Pos 425 A and 17 V with 13.5 mΩ resistance (file 060).

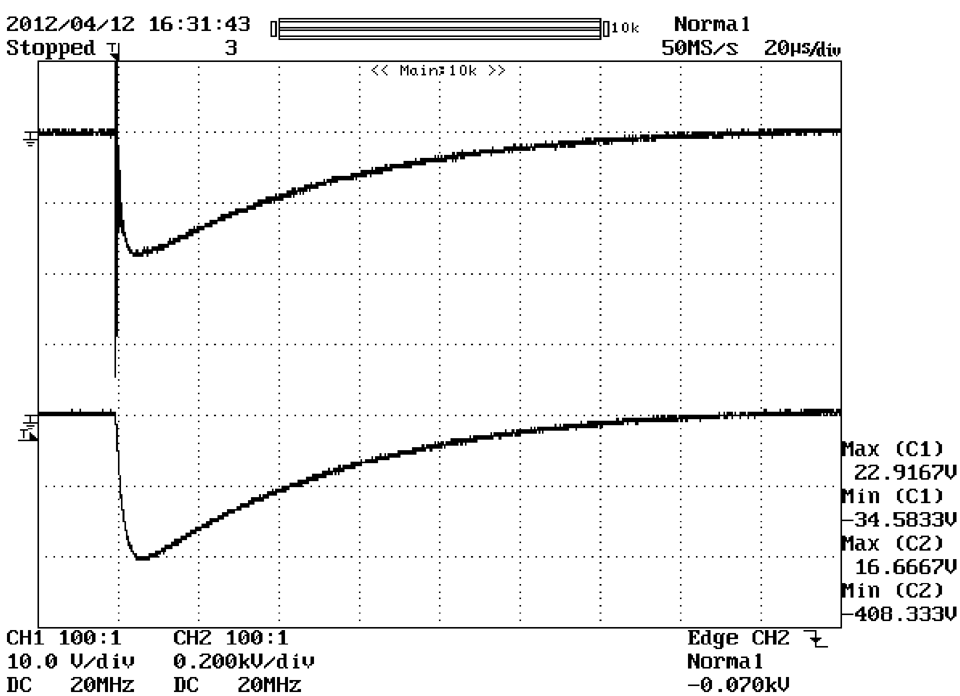


Figure G-96: LS-23 WFM 4 & 1 level 3 Neg -408 A and 17 V with 13.5 mΩ resistance (file 061).

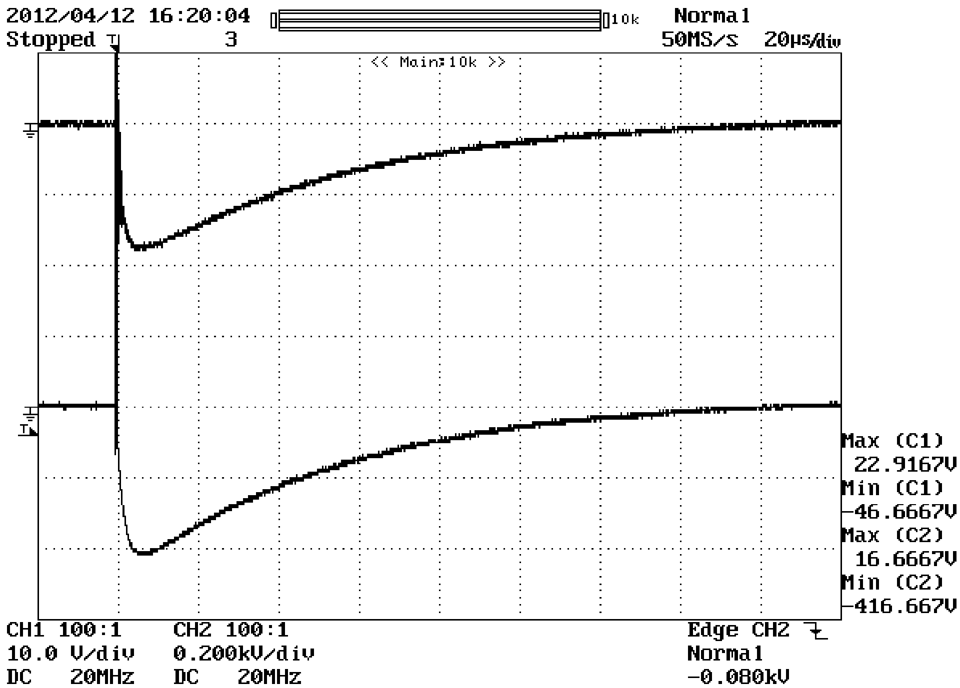


Figure G-97: LS-24 WFM 4 & 1 level 3 Neg -416 A and 17 V with 8.4 mΩ resistance (file 058).

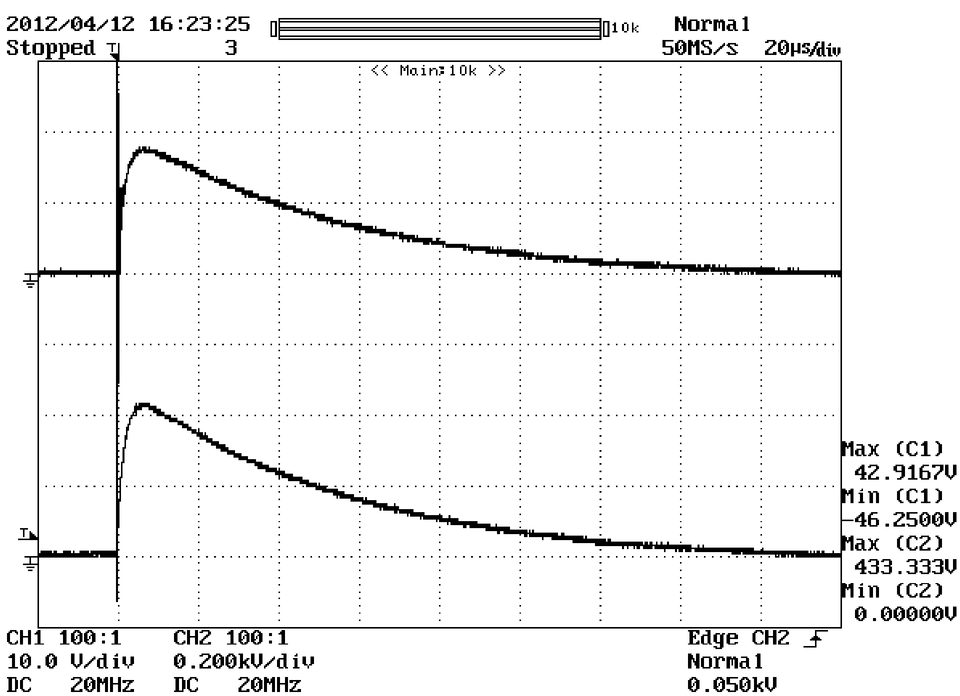


Figure G-98: LS-24 WFM 4 & 1 level 3 Pos 433 A and 17 V with 8.4 mΩ resistance (file 059).

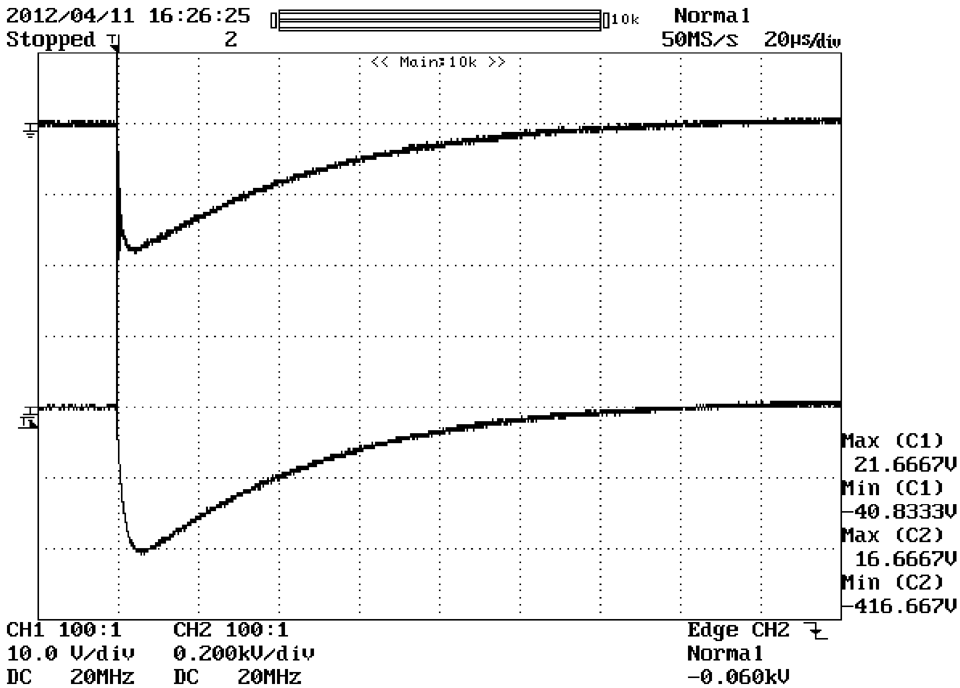


Figure G-99: LS-25 WFM 4 & 1 level 3 Neg -416 A and -18 V with 14.4 mΩ resistance (file 020).

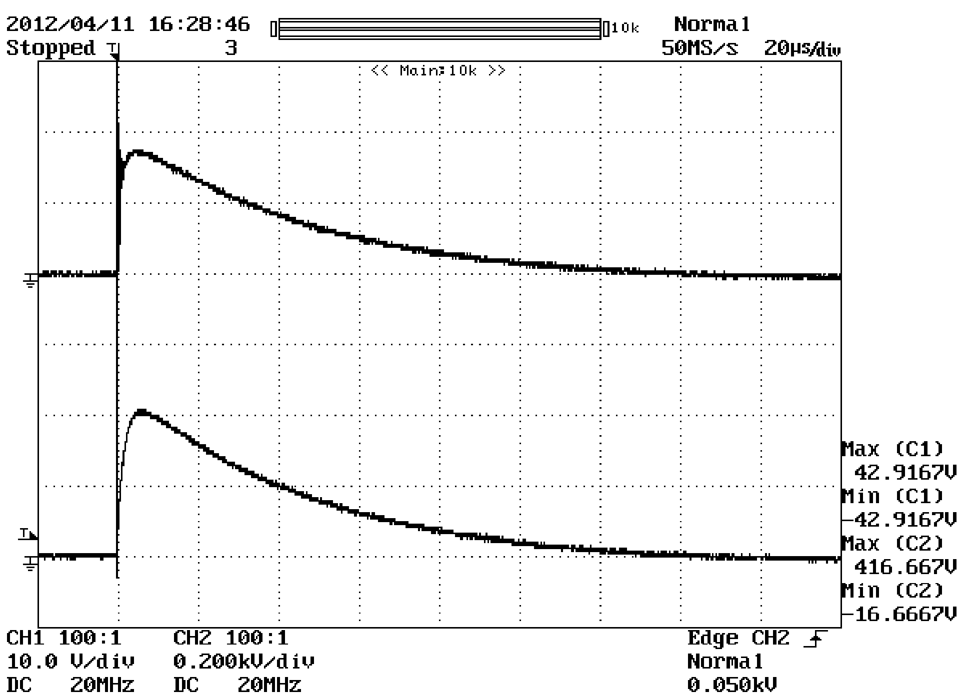


Figure G-100: LS-25 WFM 4 & 1 level 3 Pos 416 A and 17 V with 13.6 mΩ resistance (file 021).

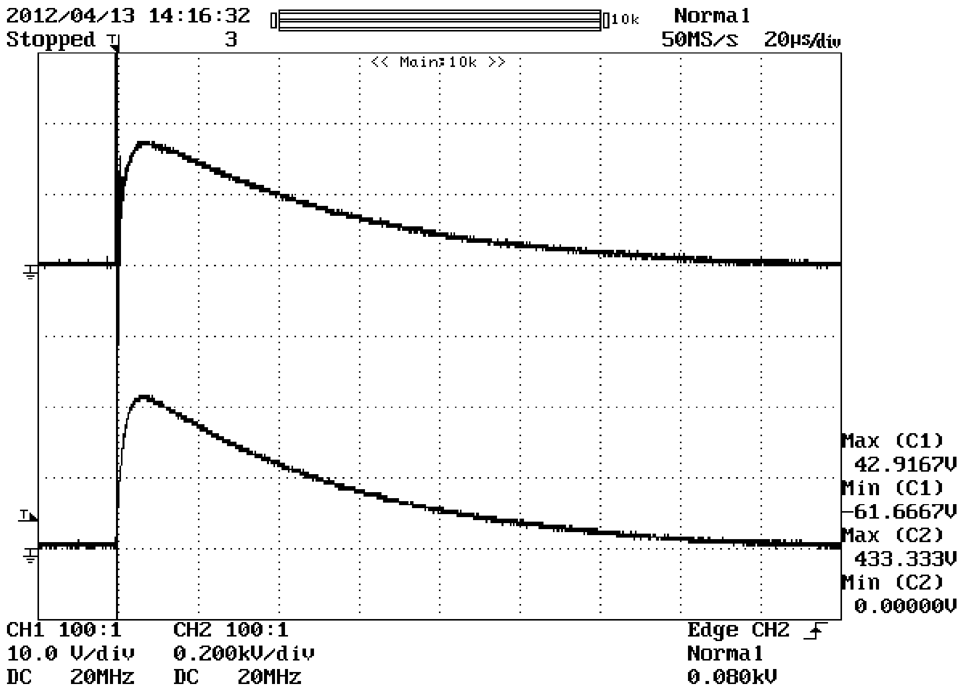


Figure G-101: LS-26 WFM 4 & 1 level 3 Pos 433 A and 17 V with 6.7 mΩ resistance (file 082).

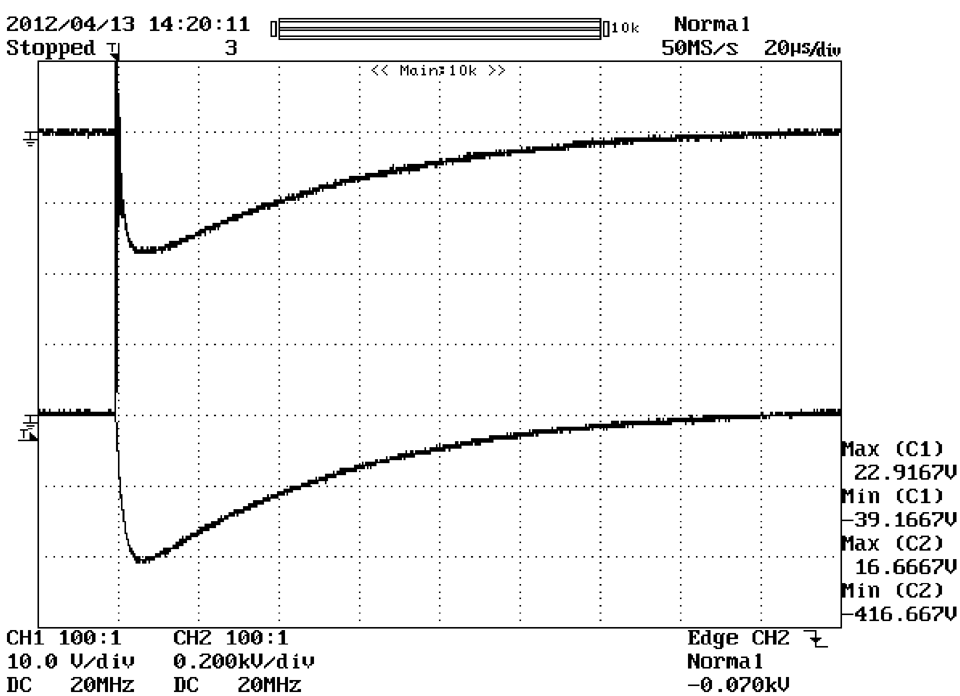


Figure G-102: LS-26 WFM 4 & 1 level 3 Neg -416 A and 17 V with 6.7 mΩ resistance (file 083).

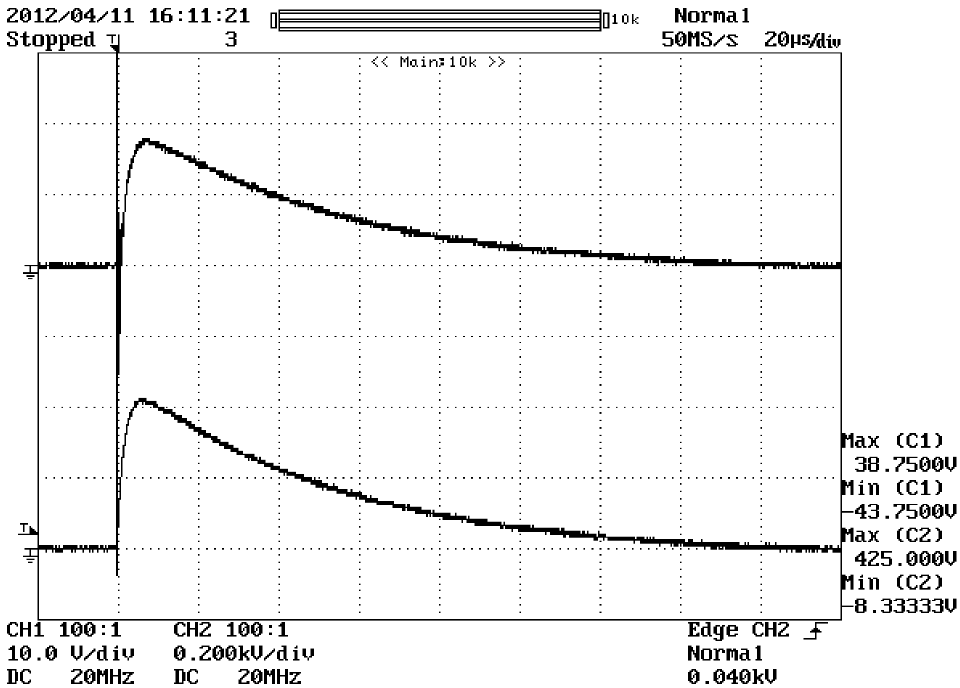


Figure G-103: LS-27 WFM 4 & 1 level 3 Pos 425 A and 18 V with 8.4 mΩ resistance (file 018).

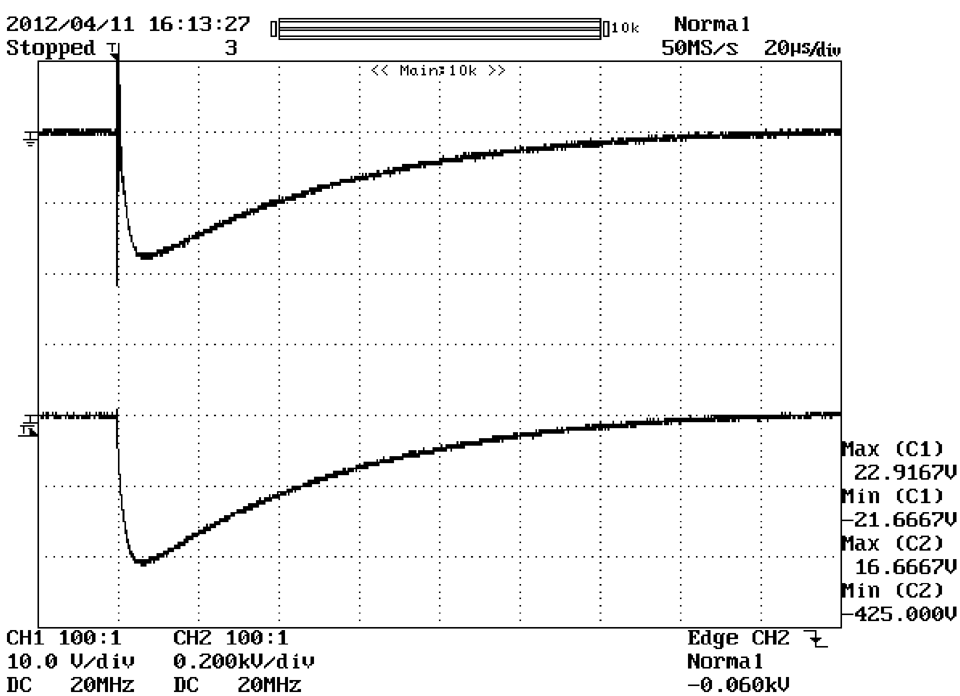


Figure G-104: LS-27 WFM 4 & 1 level 3 Neg -425 A and -18 V with 14.4 mΩ resistance (file 019).

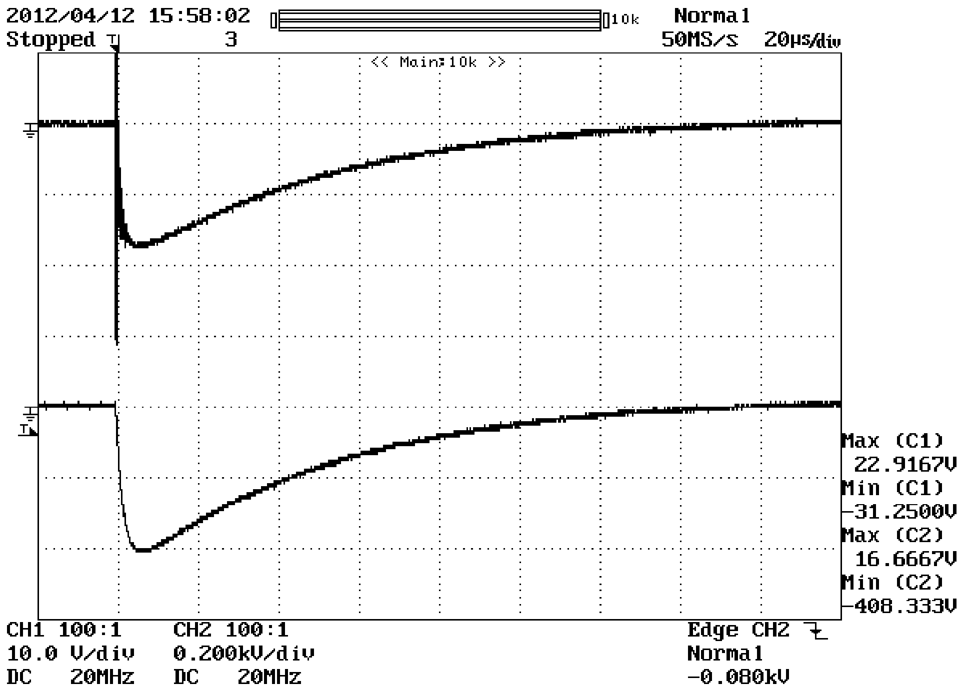


Figure G-105: LS-28 WFM 4 & 1 level 3 Neg -408 A and 17 V with 11.2 mΩ resistance (file 054).

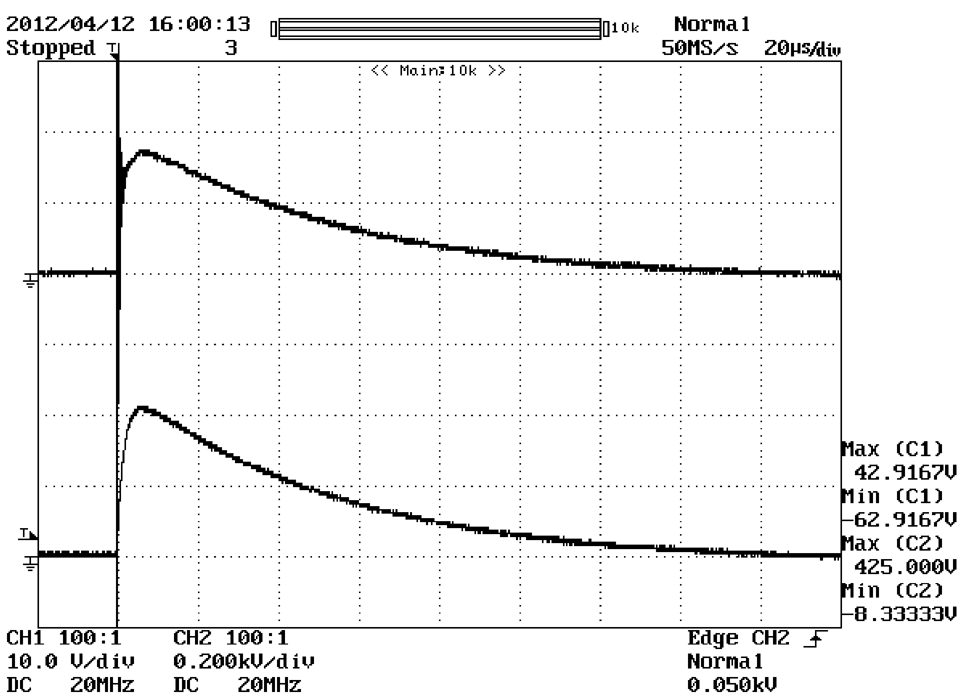


Figure G-106: LS-28 WFM 4 & 1 level 3 Pos 425 A and 17 V with 11.2 mΩ resistance (file 055).

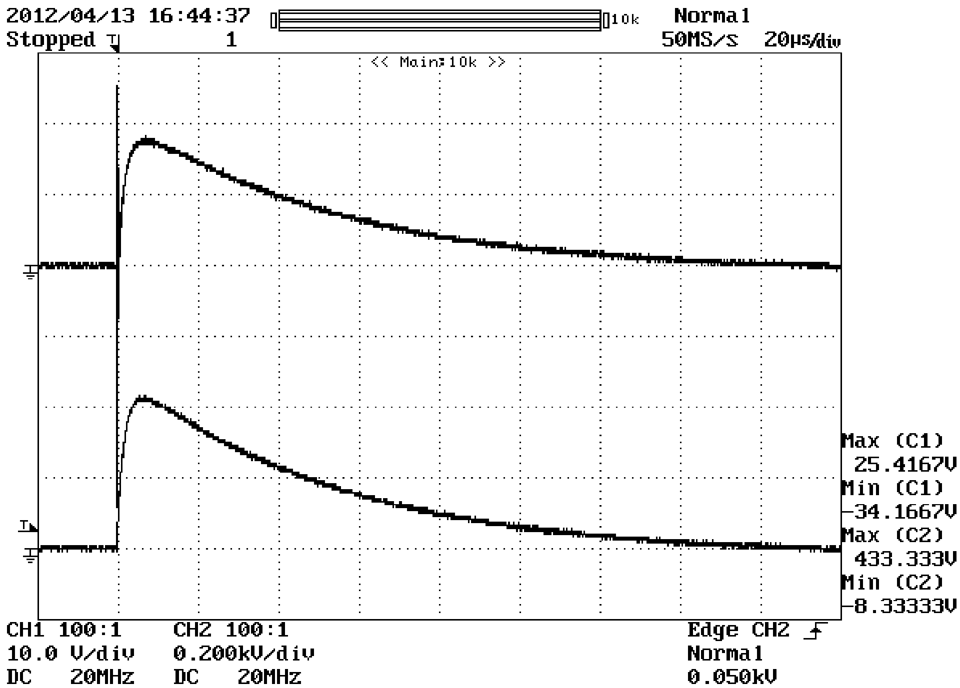


Figure G-107: LS-29 WFM 4 & 1 level 3 Pos 433 A and 17 V with 12.8 mΩ resistance (file 094).

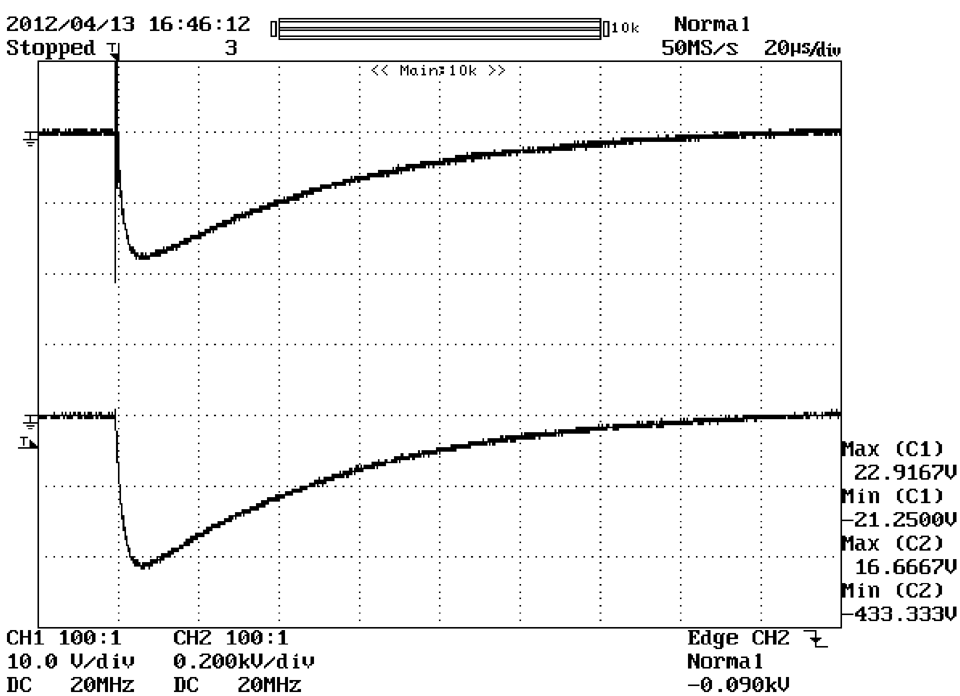


Figure G-108: LS-29 WFM 4 & 1 level 3 Neg -433 A and 17 V with 12.8 mΩ resistance (file 095).

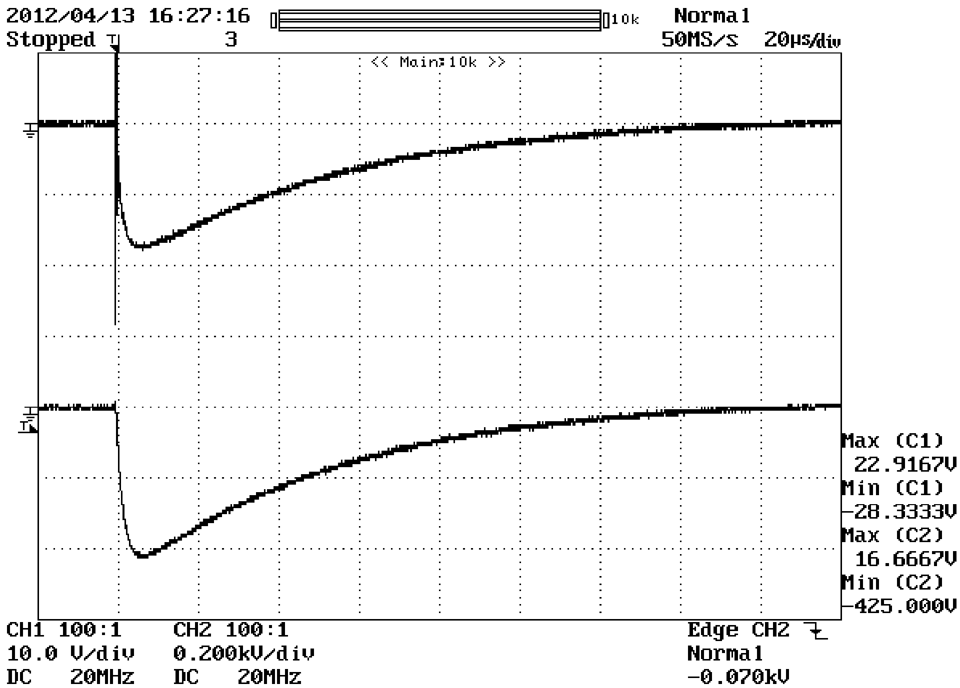


Figure G-109: LS-30 WFM 4 & 1 level 3 Neg -425 A and 17 V with 12.3 mΩ resistance (file 092).

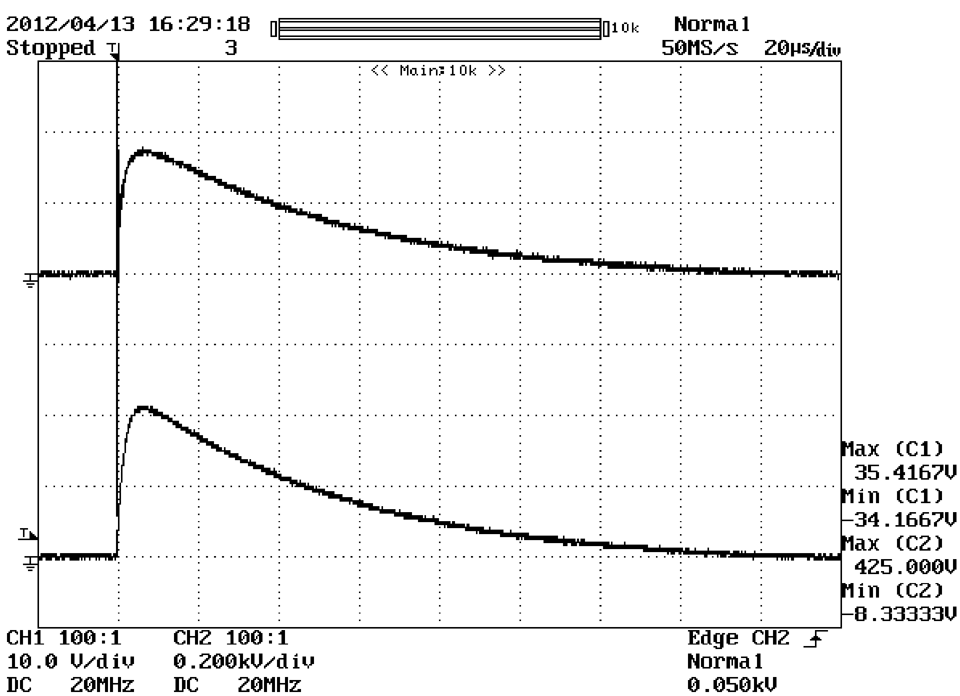


Figure G-110: LS-30 WFM 4 & 1 level 3 Pos 425 A and 17 V with 12.3 mΩ resistance (file 093).

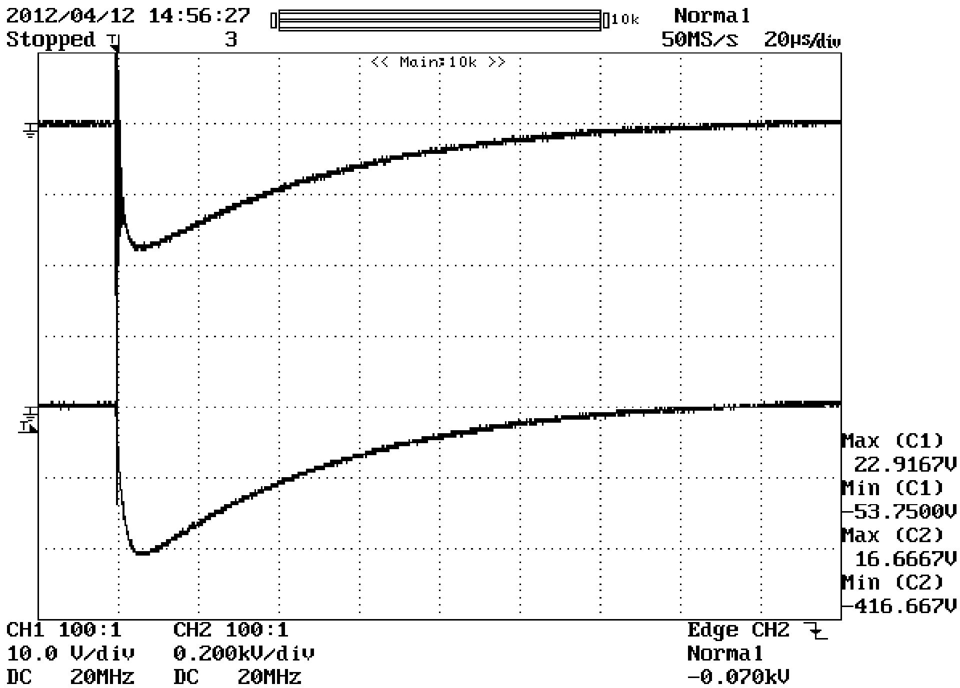


Figure G-111: LS-32 WFM 4 & 1 level 3 Neg -416 A and 17 V with 11.7 mΩ resistance (file 050).

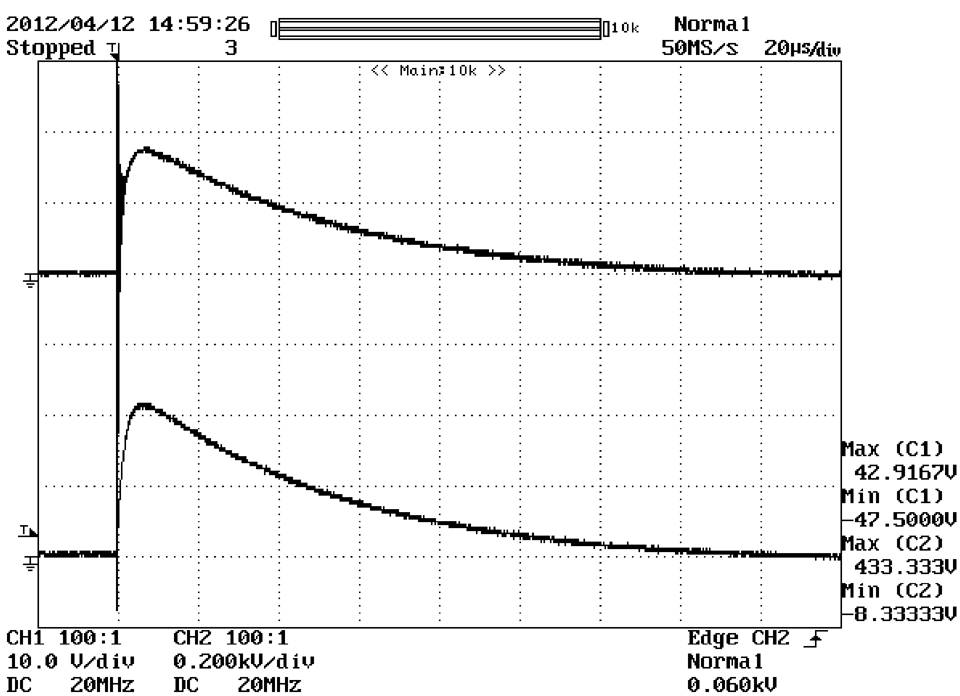


Figure G-112: LS-32 WFM 4 & 1 level 3 Pos 433 A and 17 V with 11.7 mΩ resistance (file 051).

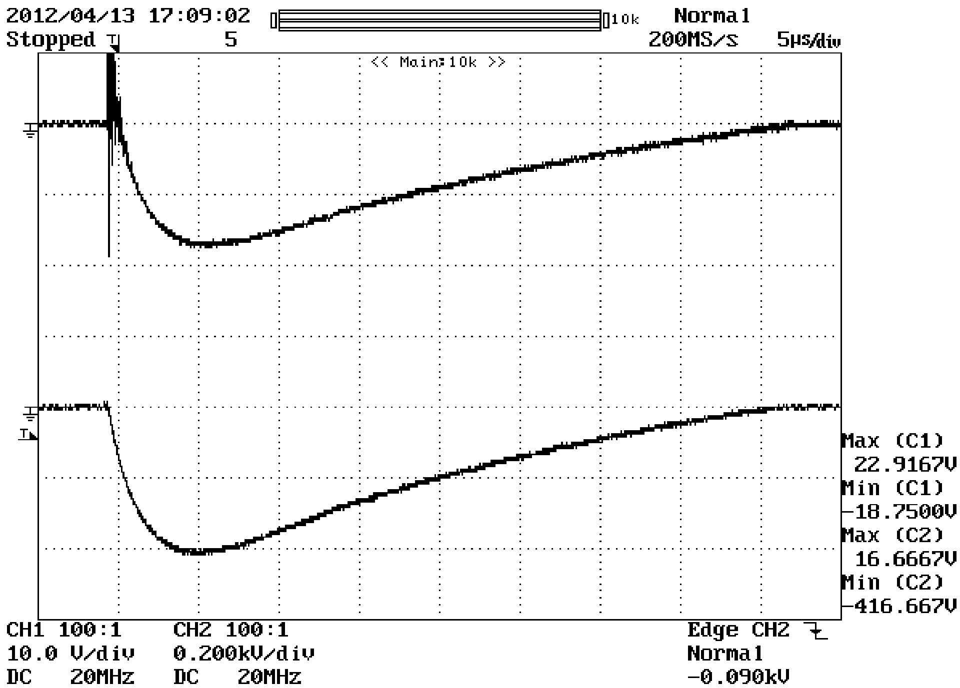


Figure G-113: LS-33 WFM 4 & 1 level 3 Neg -416 A and 17 V with 20.4 mΩ resistance (file 096).

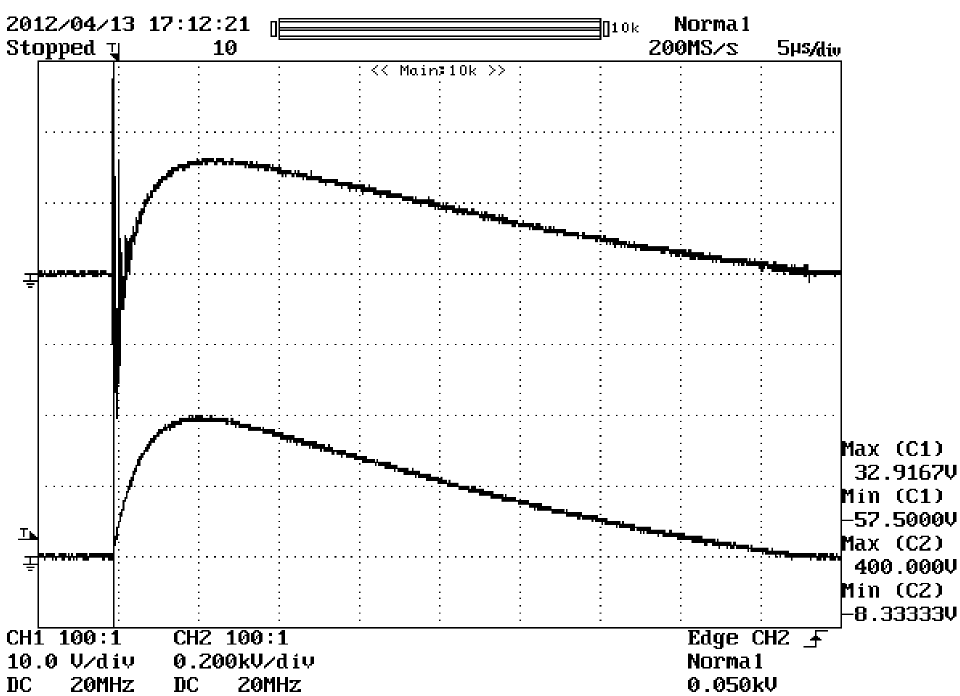


Figure G-114: LS-33 WFM 4 & 1 level 3 Pos 400 A and 17 V with 20.4 mΩ resistance (file 097).

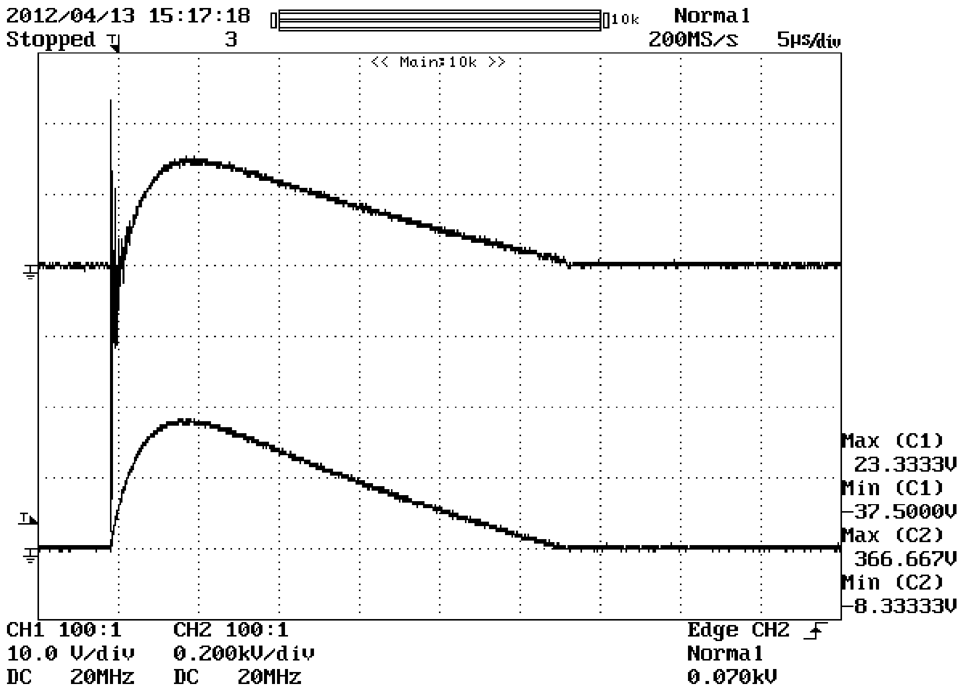


Figure G-115: LS-34 WFM 4 & 1 level 3 Pos 366 A and 17 V with 19.3 mΩ resistance (file 086).

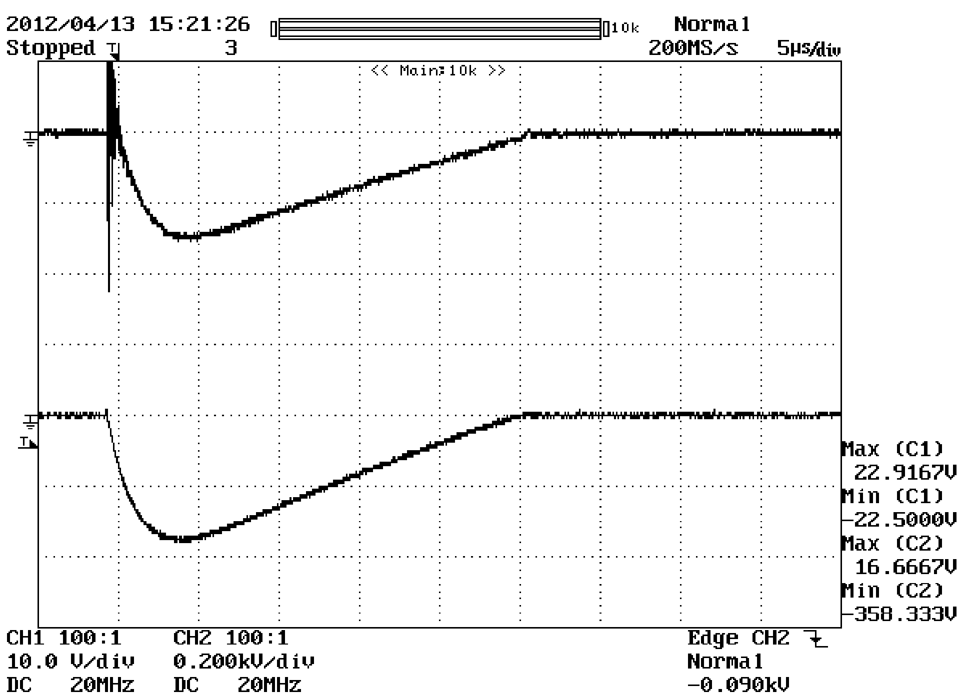


Figure G-116: LS-34 WFM 4 & 1 level 3 Neg -358 A and 17 V with 19.3 mΩ resistance (file 087).

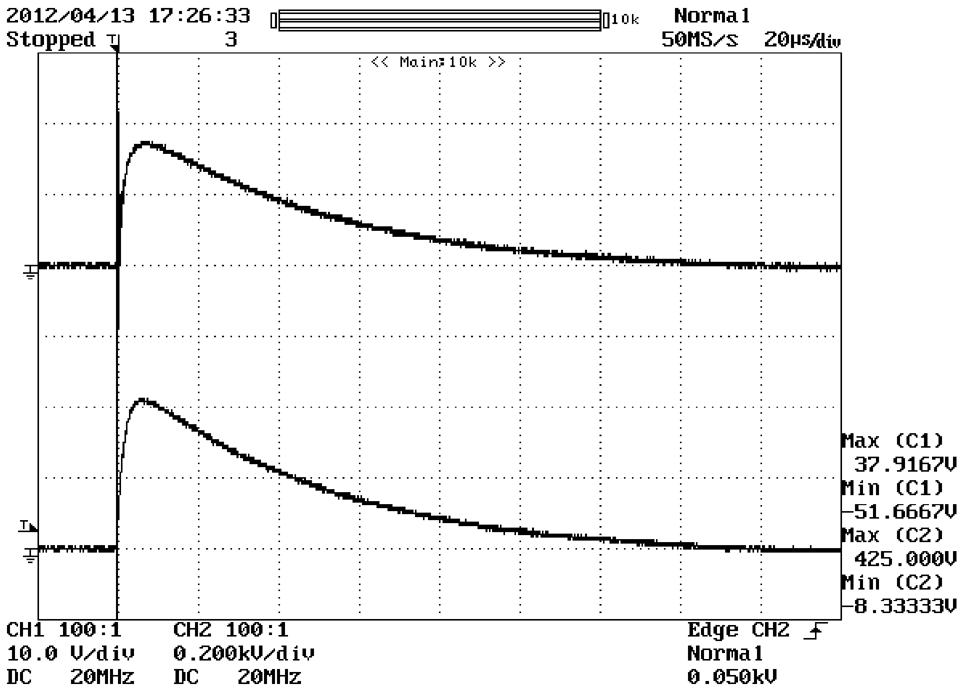


Figure G-117: LS-35 WFM 4 & 1 level 3 Pos 425 A and 17 V with 9.2 mΩ resistance (file 098).

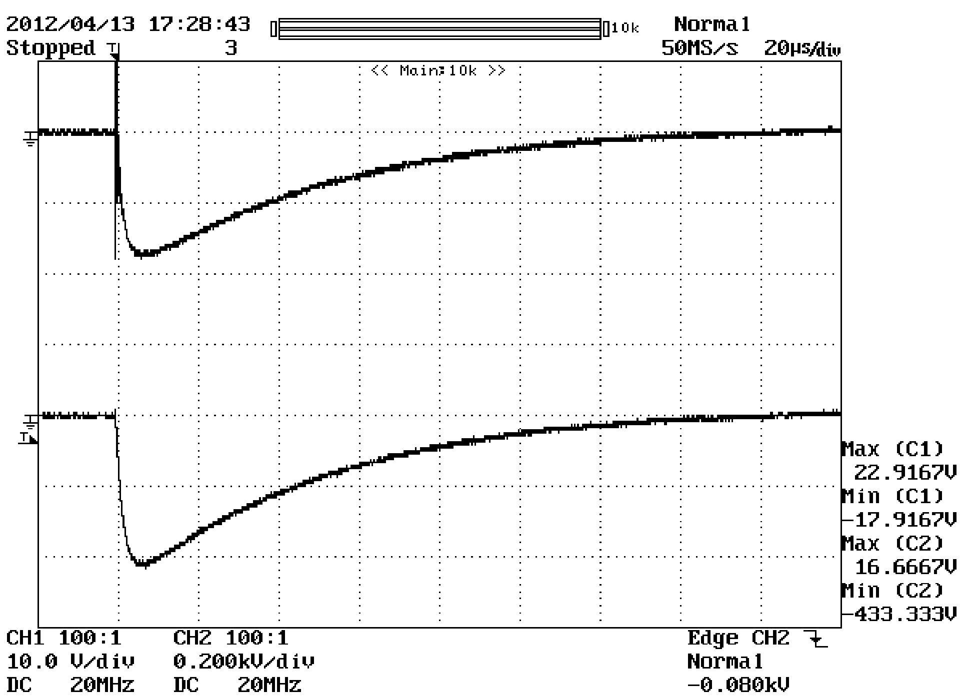


Figure G-118: LS-35 WFM 4 & 1 level 3 Neg -433 A and 17 V with 9.2 mΩ resistance (file 099).

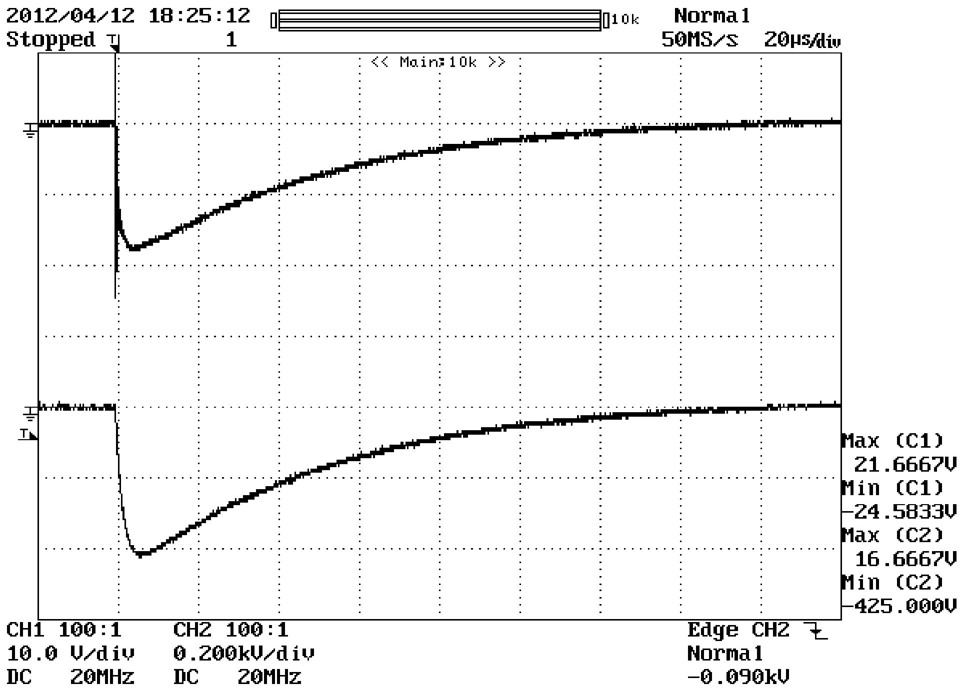


Figure G-119: LS-36 WFM 4 & 1 level 3 Neg -425 A and 17 V with 8.3 mΩ resistance (file 066).

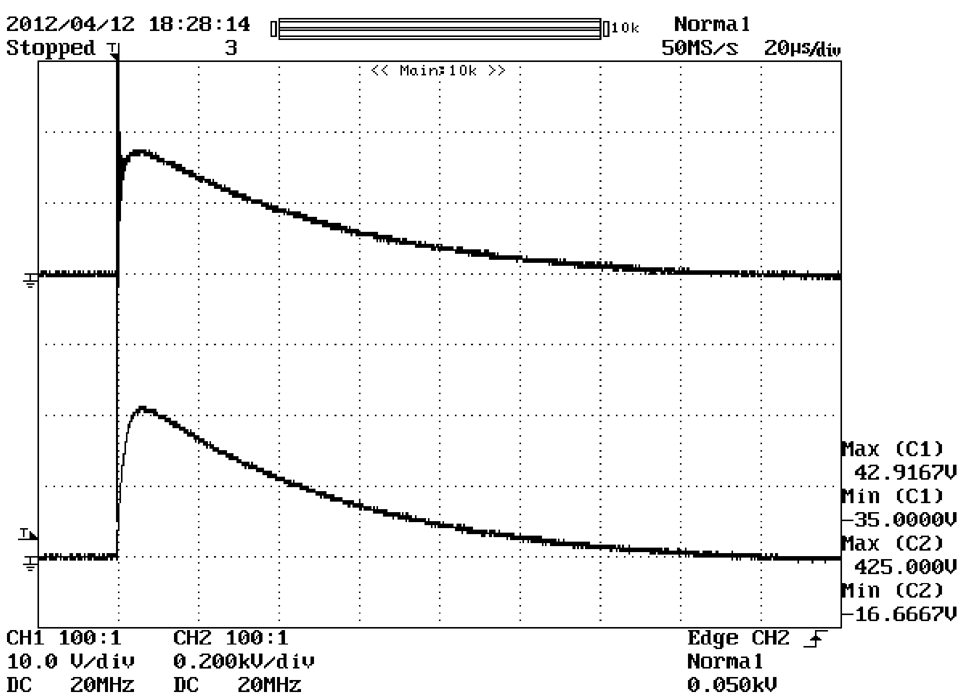
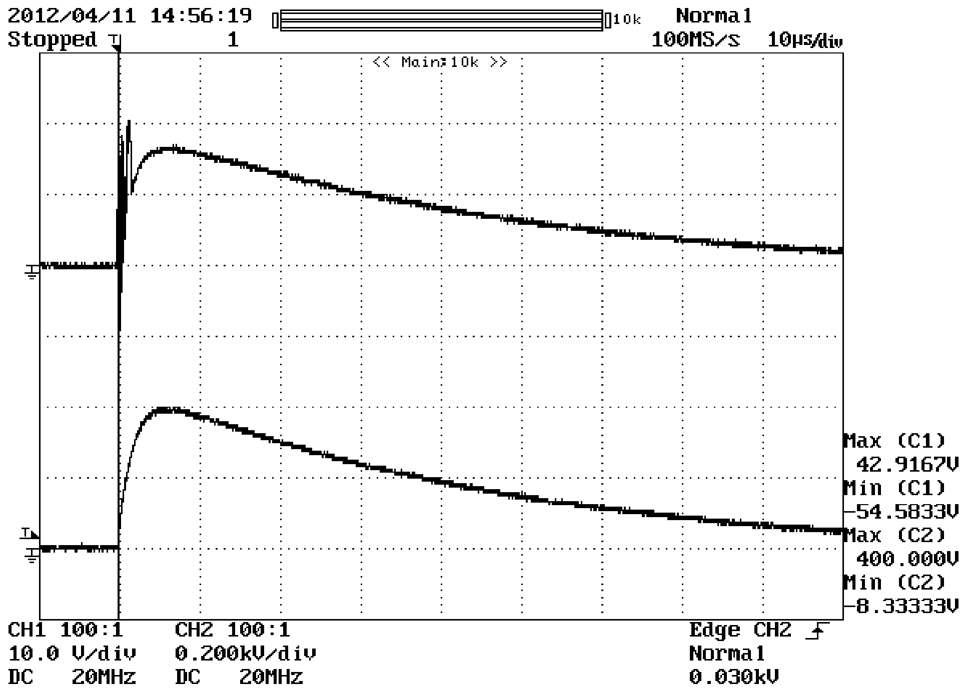


Figure G-120: LS-36 WFM 4 & 1 level 3 Pos 425 A and 17 V with 8.3 mΩ resistance (file 067).



17

Figure G-121: LS-37 WFM 4 & 1 level 3 Pos 400 A and 17 V with 13.6 mΩ resistance (file 010).

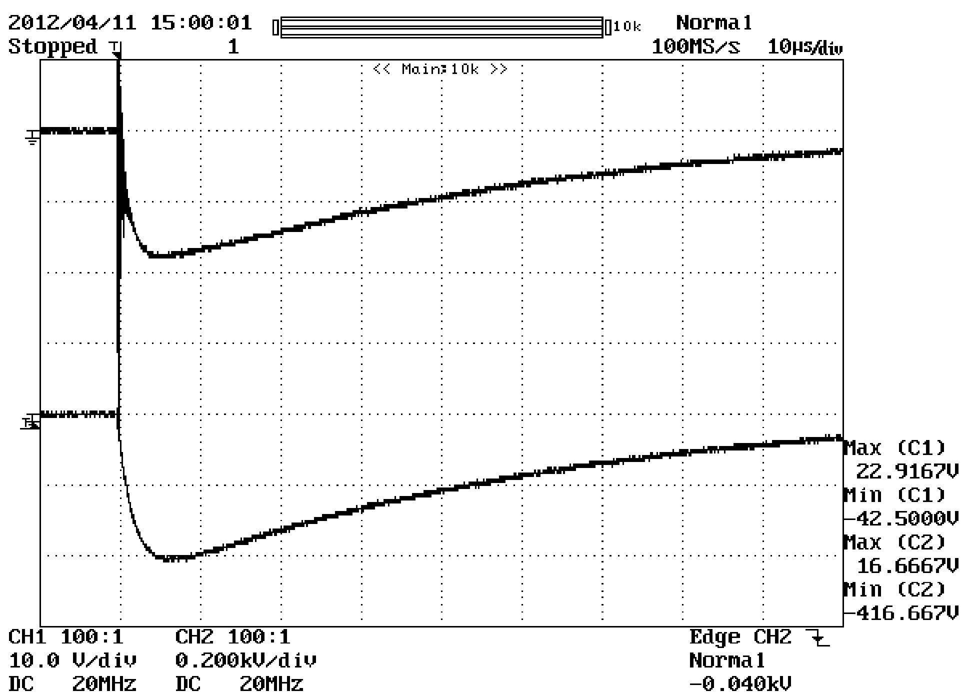


Figure G-122: LS-37 WFM 4 & 1 level 3 Neg -416 A and -18 V with 13.6 mΩ resistance (file 011).

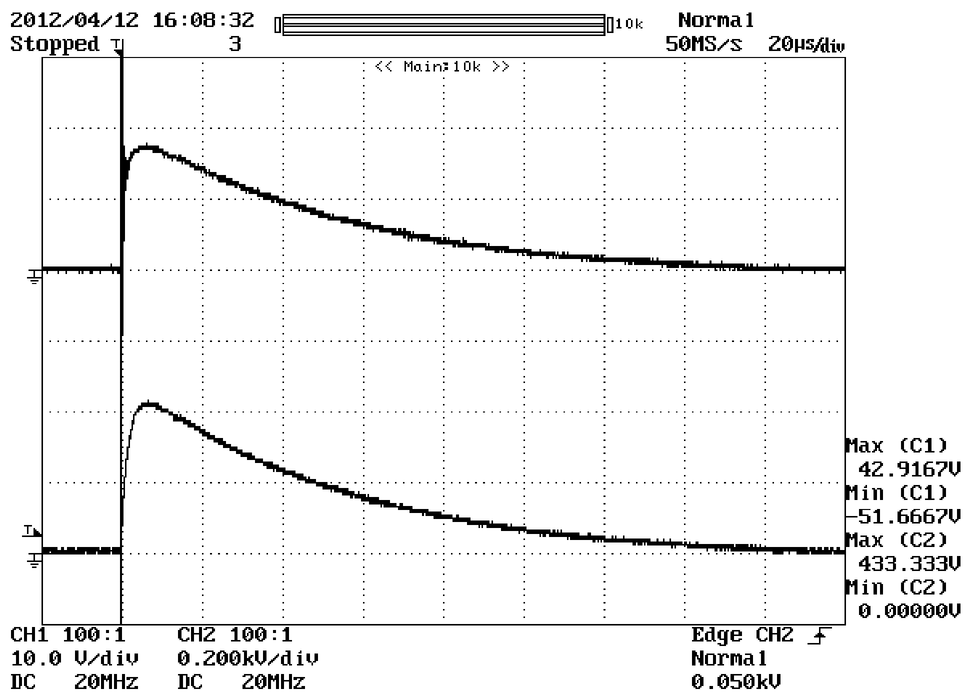


Figure G-123: LS-38 WFM 4 & 1 level 3 Pos 433 A and 17 V with 6.9 mΩ resistance (file 056).

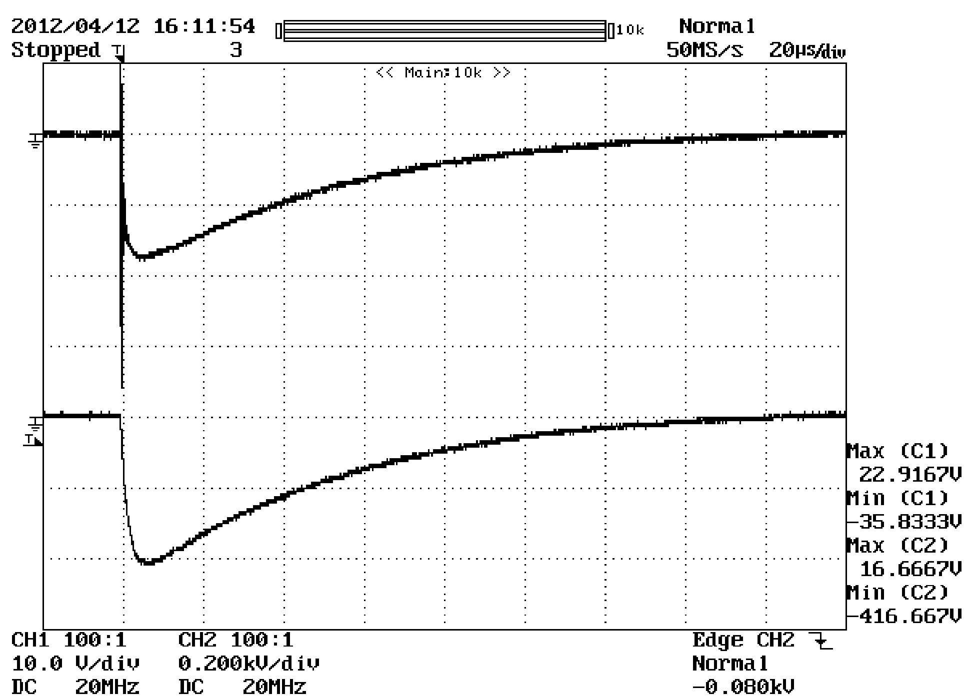


Figure G-124: LS-38 WFM 4 & 1 level 3 Neg -416 A and 17 V with 6.9 mΩ resistance (file 057).

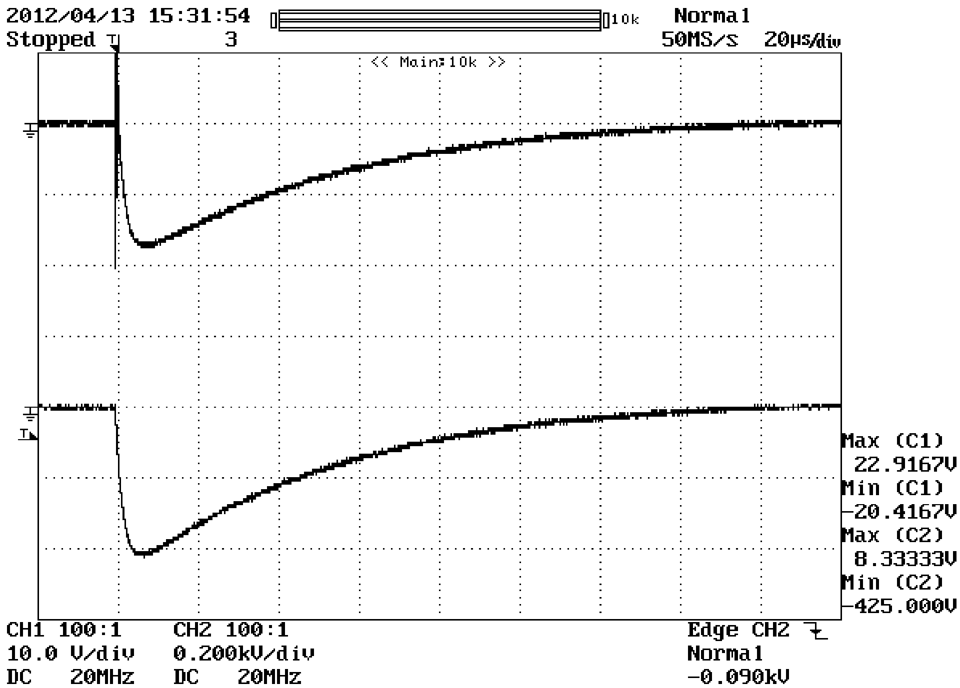


Figure G-125: LS-39 WFM 4 & 1 level 3 Neg -425 A and 17 V with 10.2 mΩ resistance (file 088).

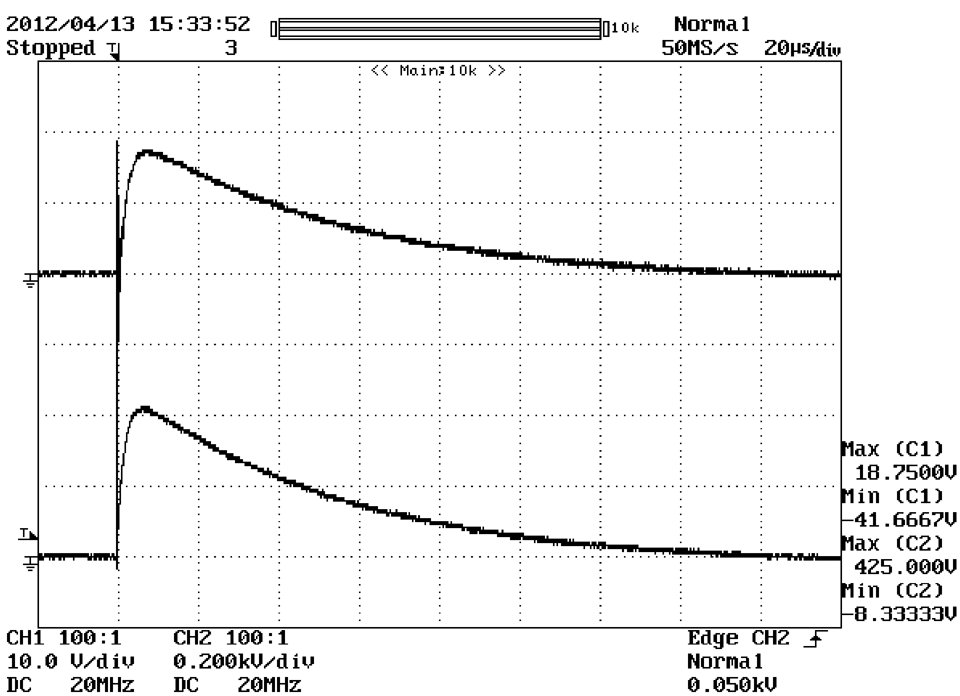


Figure G-126: LS-39 WFM 4 & 1 level 3 Pos 425 A and 17 V with 10.2 mΩ resistance (file 089).

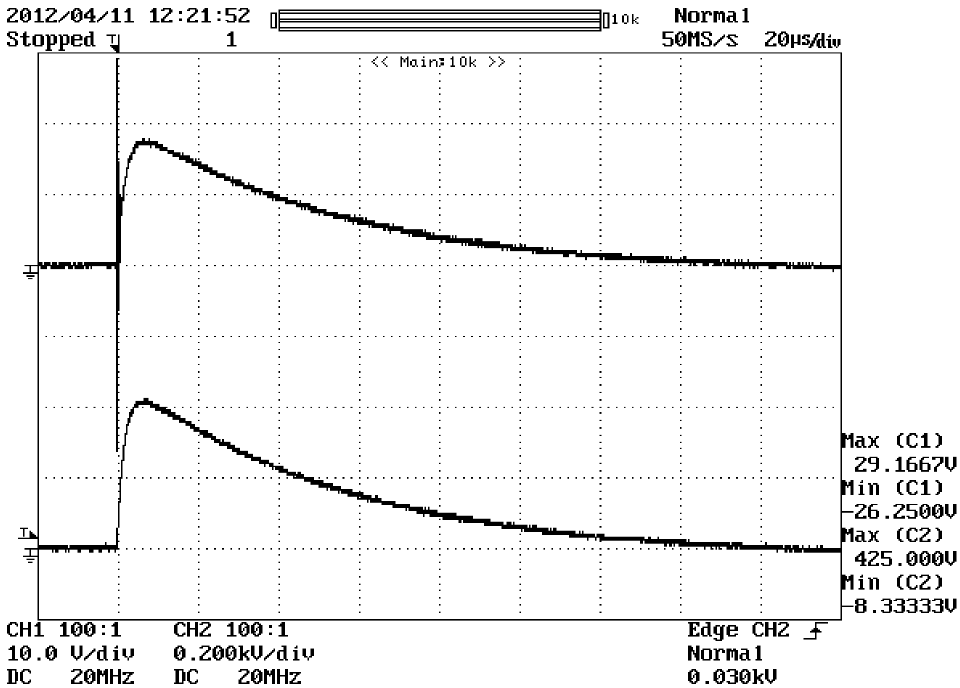


Figure G-127: LS-40 WFM 1 & 4 level 3 Pos 425 A and 18 V with 11.3 mΩ resistance file (002).

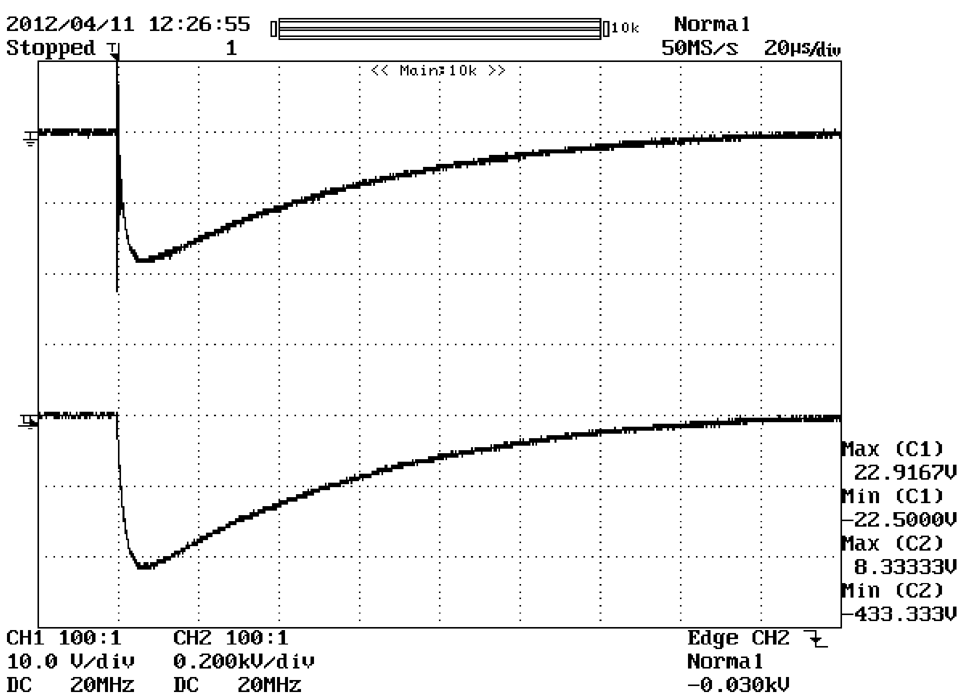


Figure G-128: LS-40 WFM 1 & 4 level 3 Neg -433 A and -19 V with 11.3 mΩ resistance file (003).

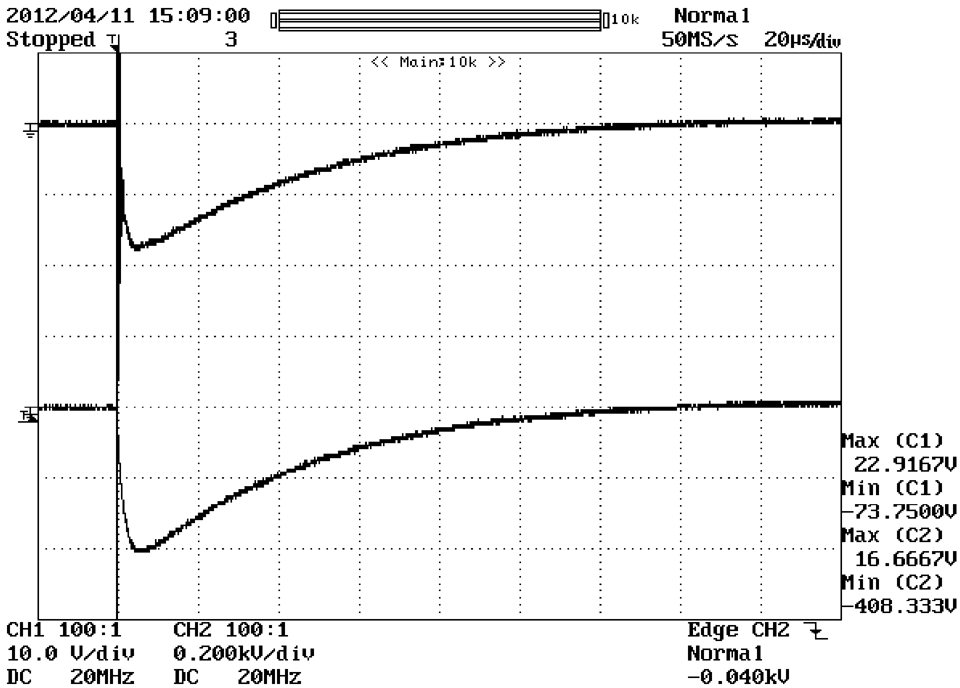


Figure G-129: LS-41 WFM 4 & 1 level 3 Neg -408 A and -18 V with 14.6 mΩ resistance (file 012).

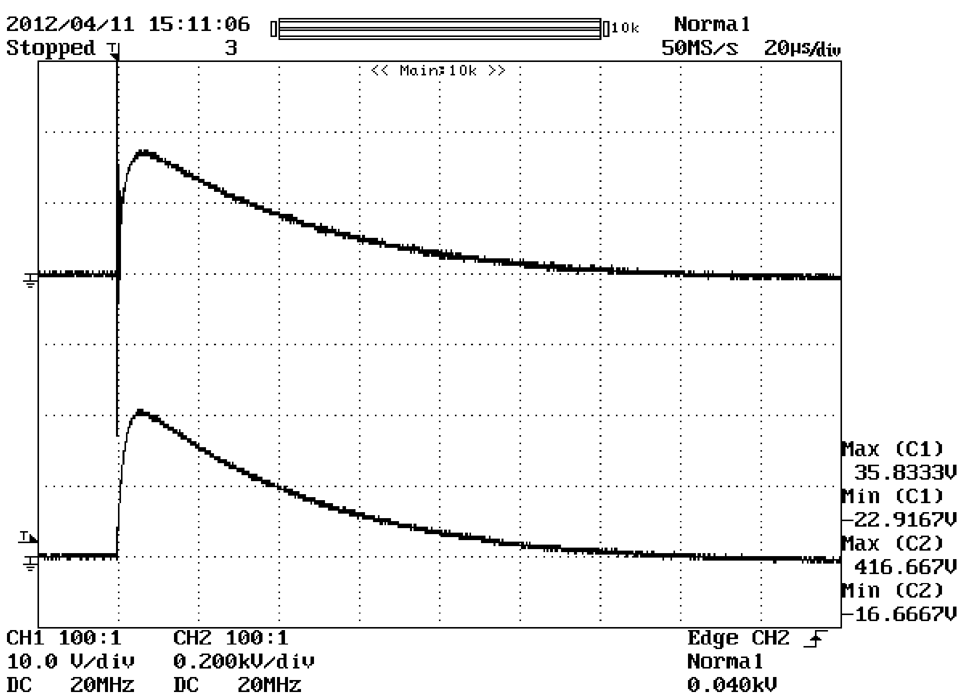


Figure G-130: LS-41 WFM 4 & 1 level 3 Pos 416 A and 18 V with 14.6 mΩ resistance (file 013).

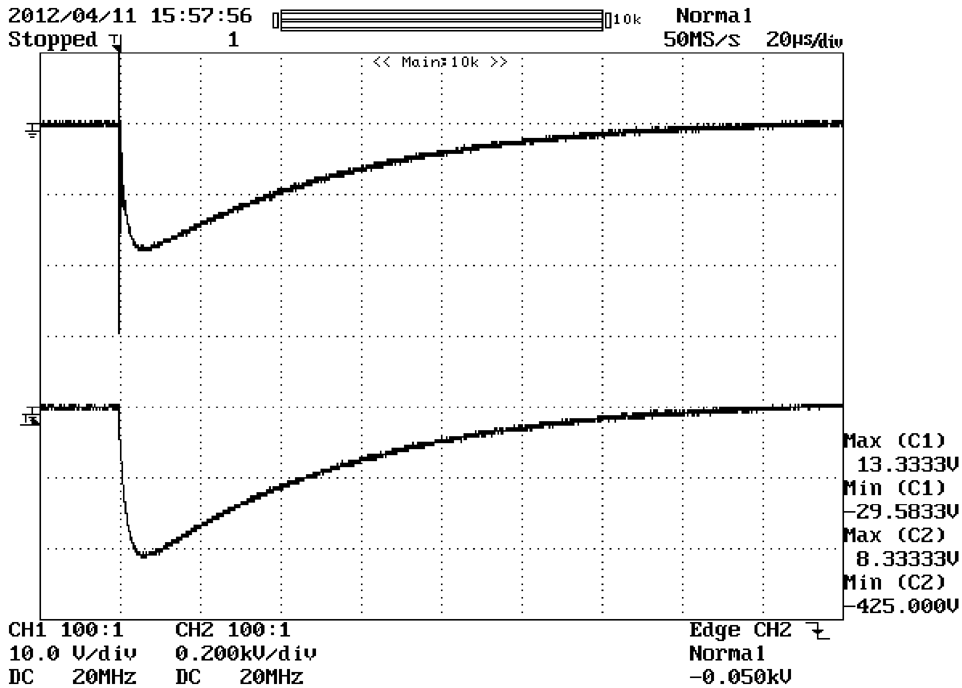


Figure G-131: LS-42 WFM 4 & 1 level 3 Neg -425 A and -18 V with 6.6 mΩ resistance (file 016).

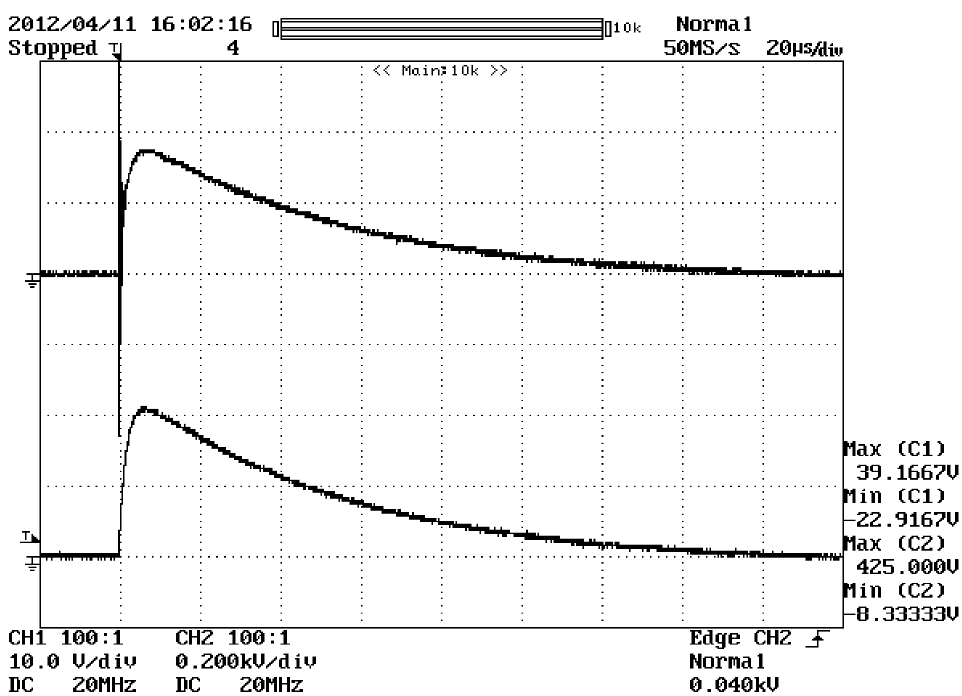


Figure G-132: LS-42 WFM 4 & 1 level 3 Pos 425 A and 18 V with 6.6 mΩ resistance (file 017).

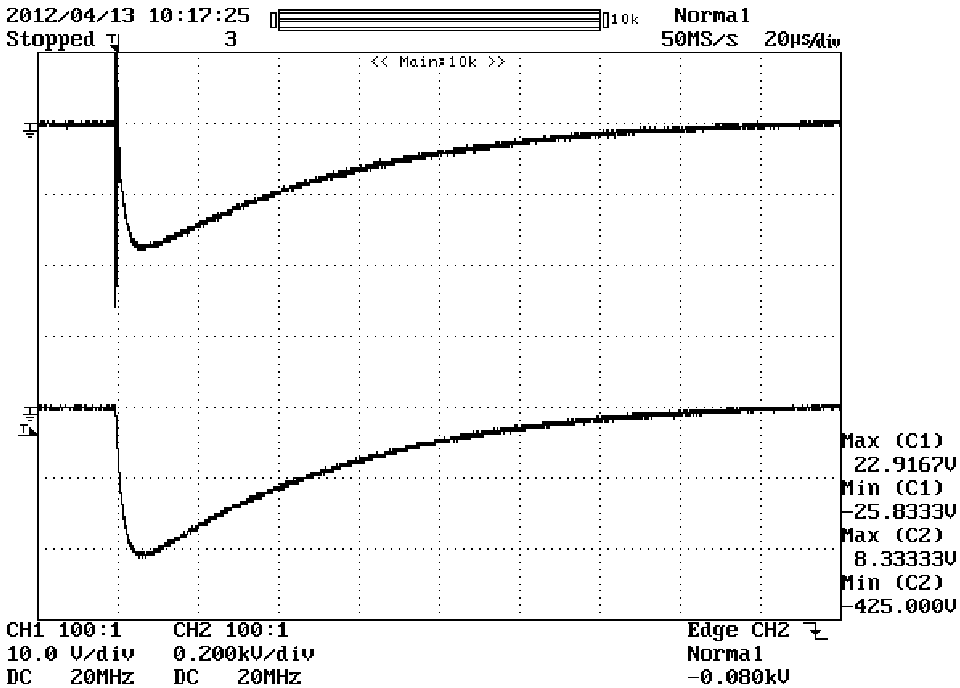


Figure G-133: LS-43 WFM 4 & 1 level 3 Neg -425 A and 17 V with 7.4 mΩ resistance (file 072).

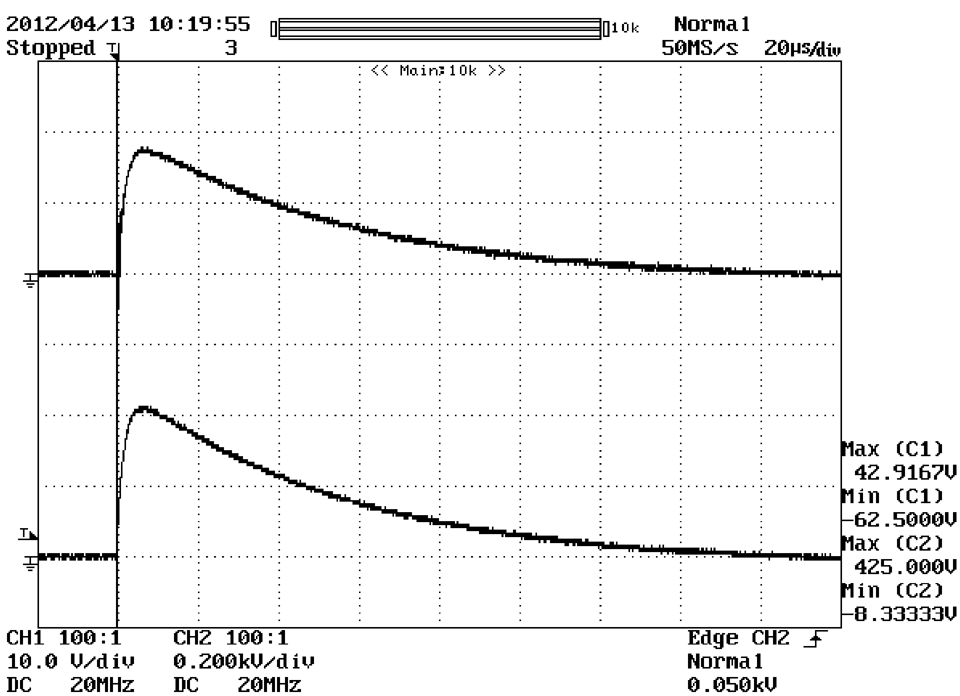


Figure G-134: LS-43 WFM 4 & 1 level 3 Neg 425 A and 17 V with 7.4 mΩ resistance (file 073).

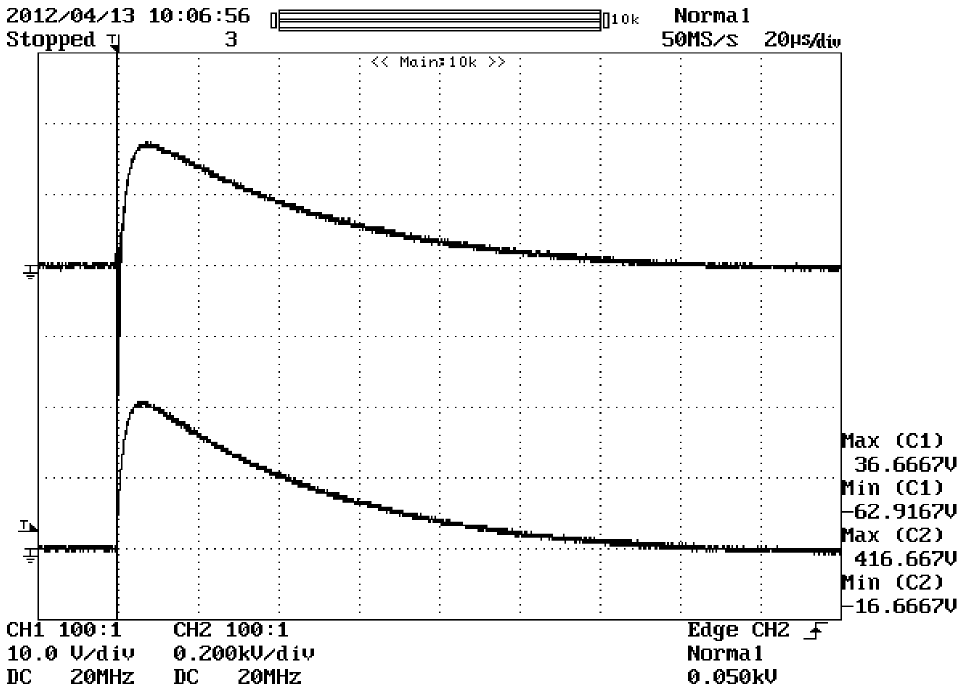


Figure G-135: LS-44 WFM 4 & 1 level 3 Pos 416 A and 17 V with 13.2 mΩ resistance (file 070).

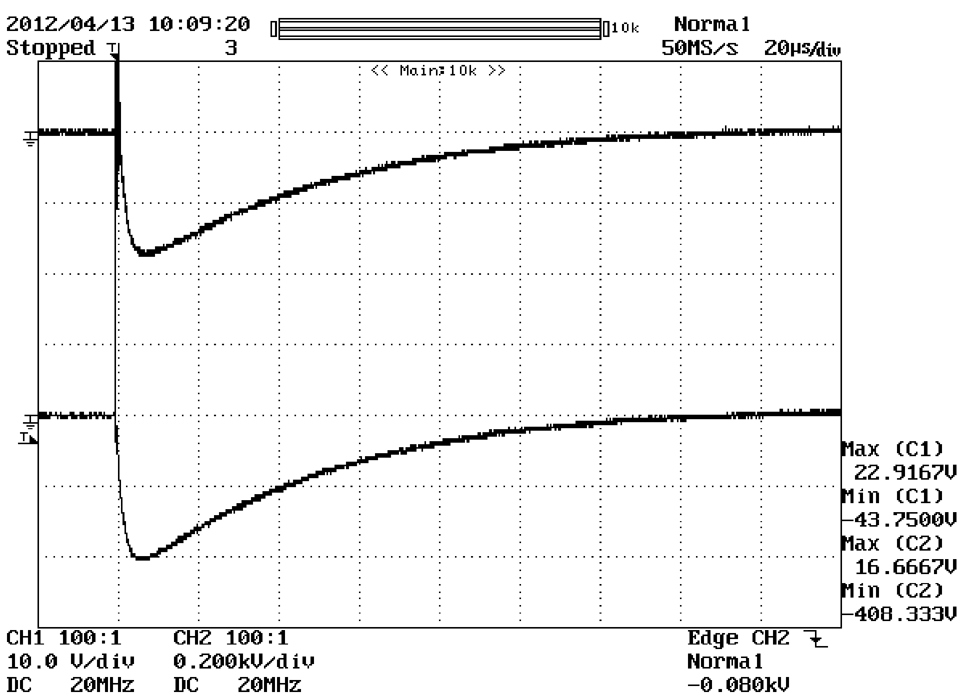


Figure G-136: LS-44 WFM 4 & 1 level 3 Neg -408 A and 17 V with 13.2 mΩ resistance (file 071).

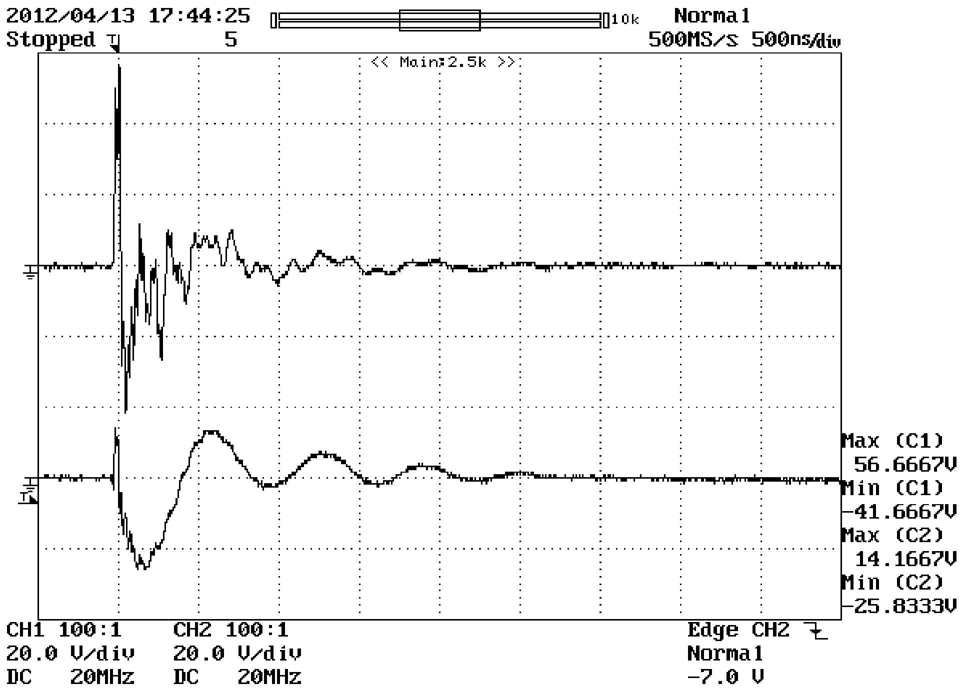


Figure G-137: LS-45 WFM 4 & 1 level 3 Neg -25 A and 17 V with 43.4 mΩ resistance (file 100).

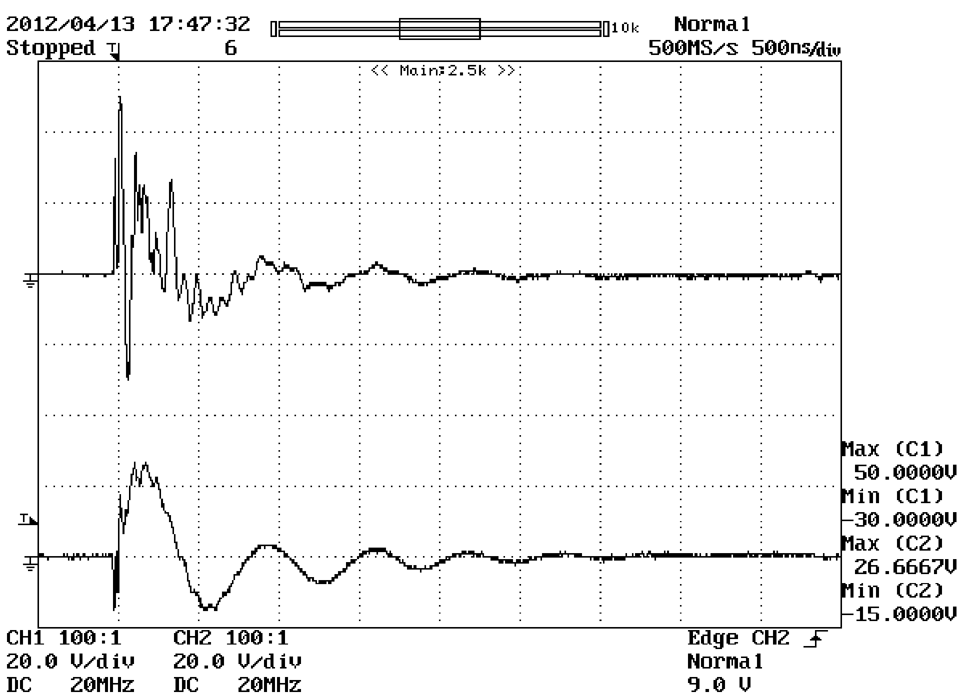


Figure G-138: LS-45 WFM 4 & 1 level 3 Pos 26 A and 17 V with 43.4 mΩ resistance (file 101).

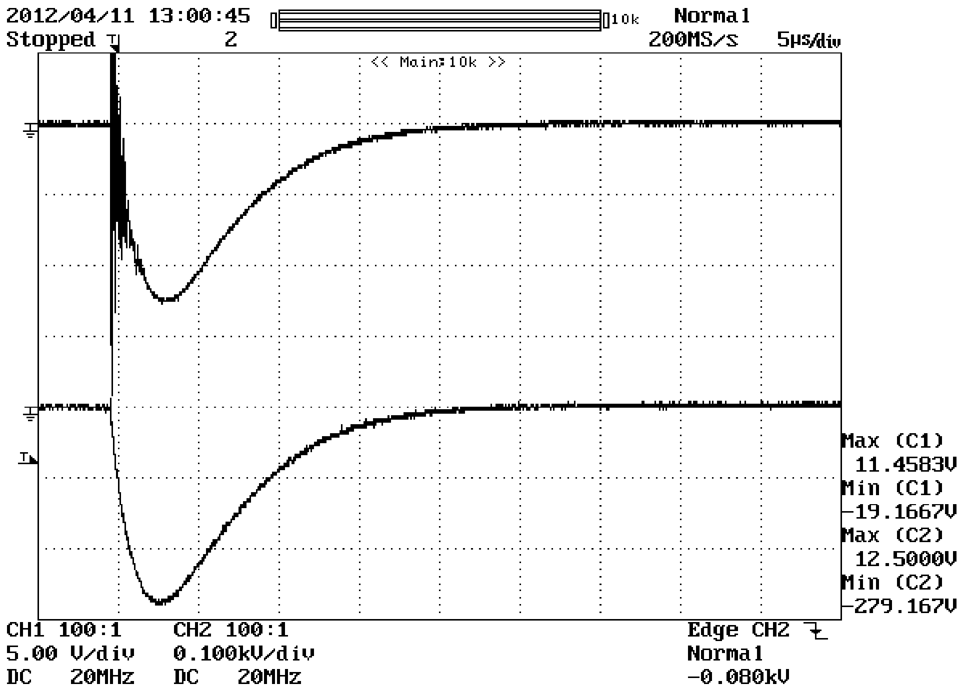


Figure G-139: LS-46 WFM 4 & 1 level 3 Neg -279 A and -12 V with 43.3 mΩ resistance file (004).

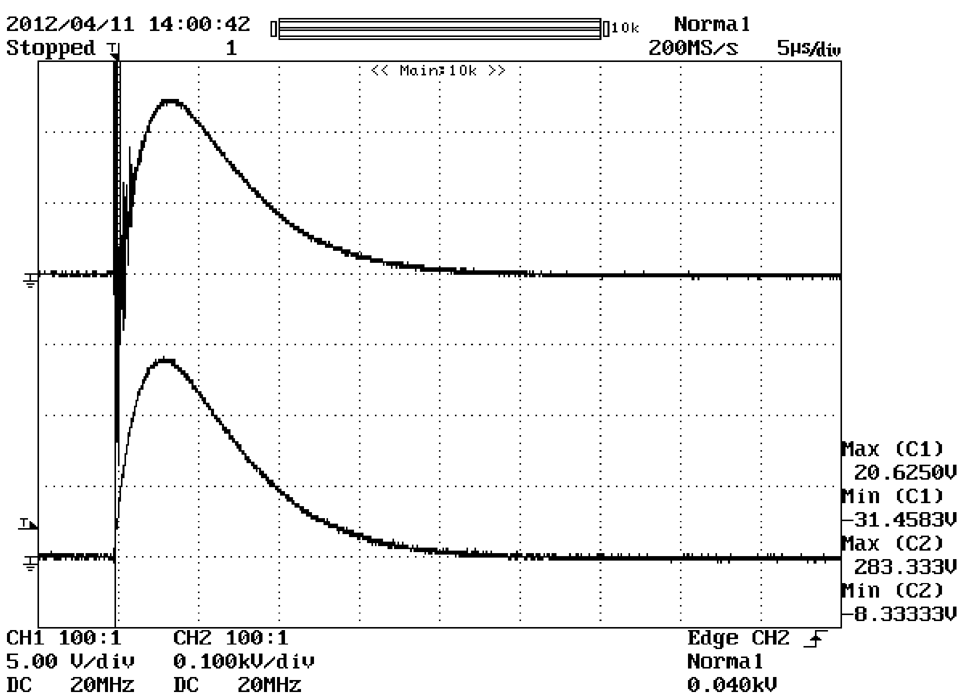


Figure G-140: LS-46 WFM 4 & 1 level 3 Pos 283 A and 12 V with 43.3 mΩ resistance file (005).

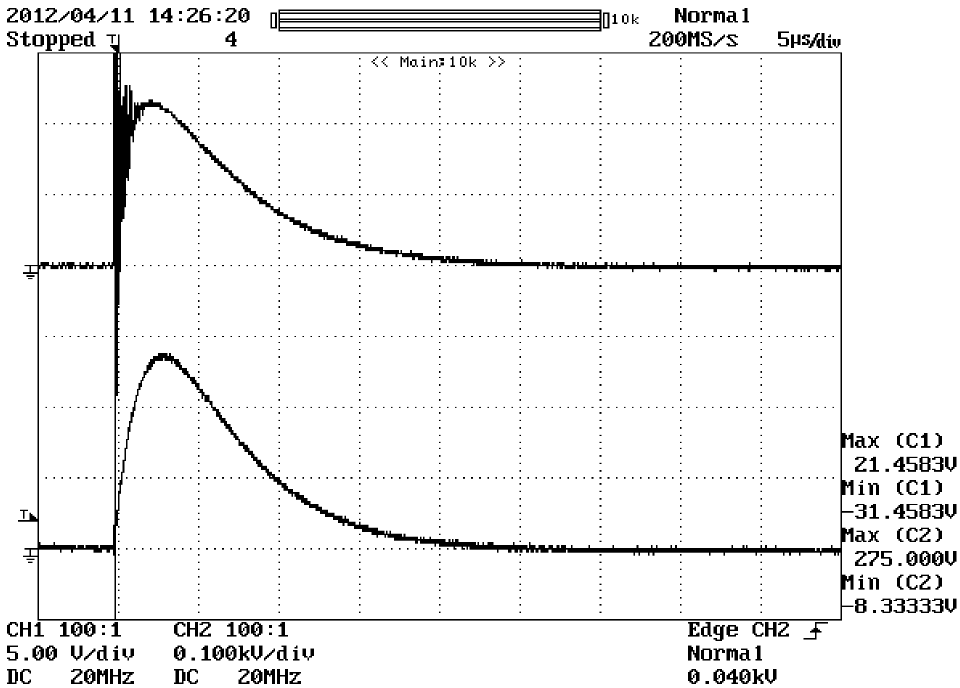


Figure G-141: LS-46 WFM 4 & 1 level 3 Pos 275 A and 12 V with 43.2 mΩ resistance file (006).

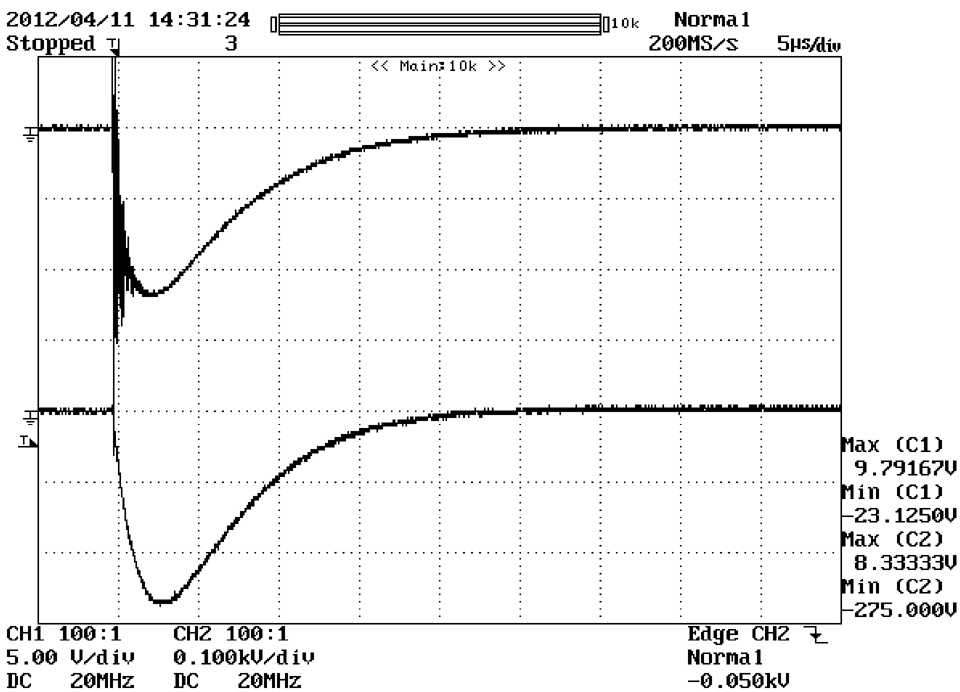


Figure G-142: LS-46 WFM 4 & 1 level 3 Neg -275 A and -12 V with 43.2 mΩ resistance file (007).

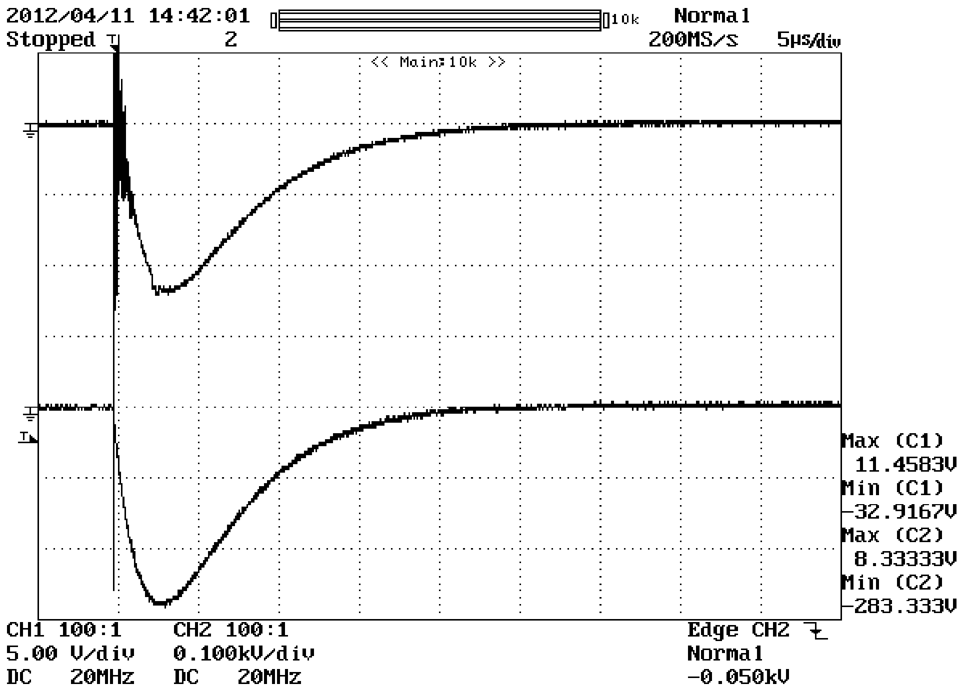


Figure G-143: LS-46 WFM 1 & 4 level 3 Neg -283 A and -12 V with 40.0 mΩ resistance (file 008).

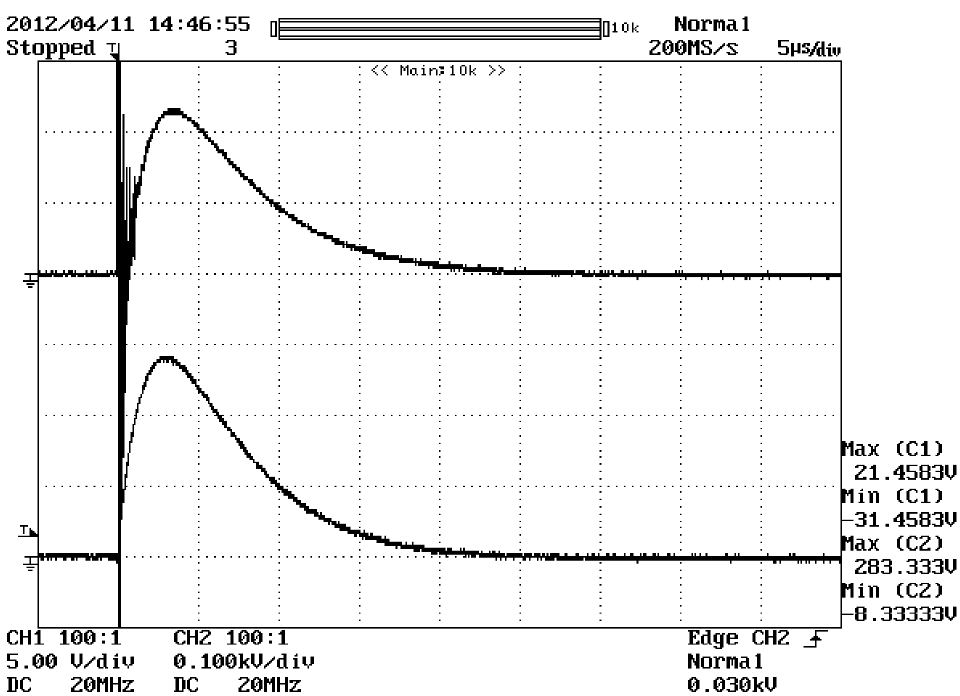


Figure G-144: LS-46 WFM 4 & 1 level 3 Pos 283 A and 12 V with 40.8 mΩ resistance (file 009).

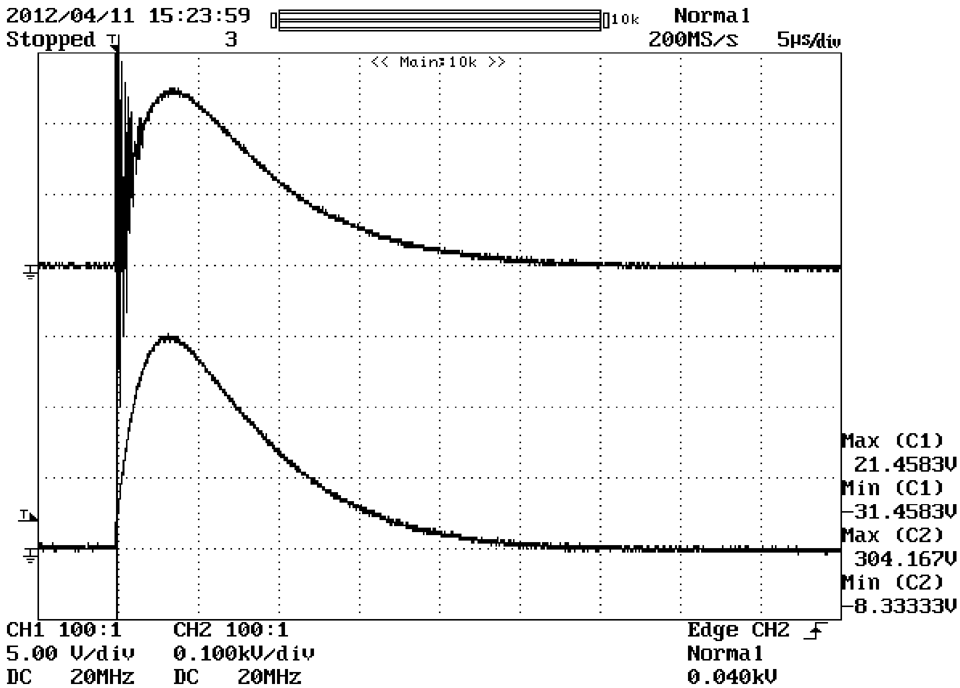


Figure G-145: LS-47 WFM 4 & 1 level 3 Pos 304 A and 13 V with 41.8 mΩ resistance (file 014).

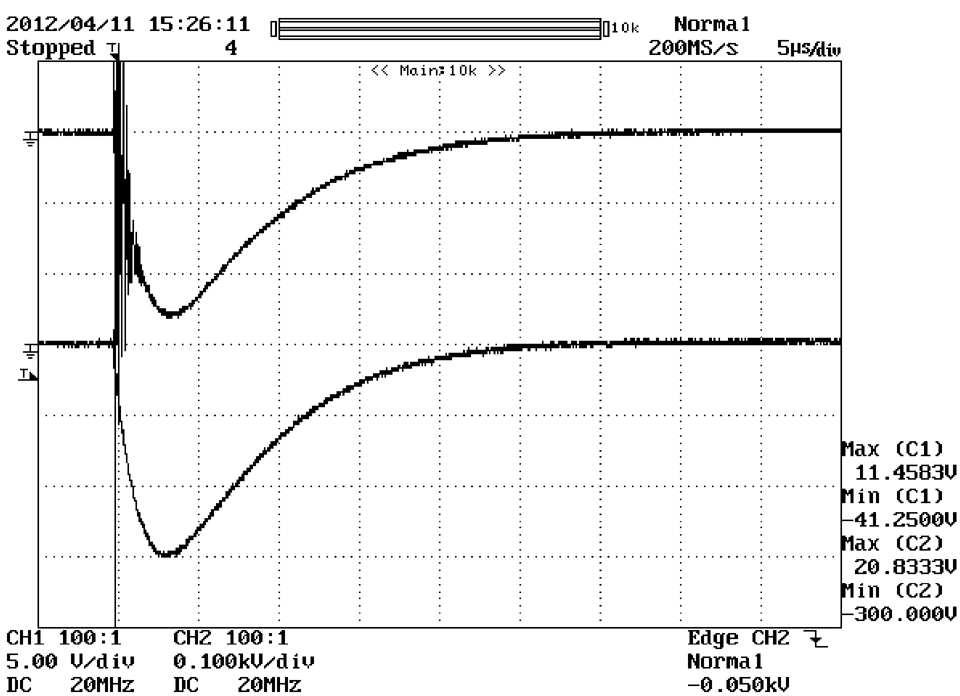


Figure G-146: LS-47 WFM 4 & 1 level 3 Neg -300 A and 13 V with 41.8 mΩ resistance (file 015).

Appendix H
First-Generation Direct Effects (DNB) Report

REVISIONS		
LTR	DESCRIPTION	DATE
-	INITIAL RELEASE	4-25-2012

	DATE	
PREPARED BY: S. COOK	4-25-12	**DNB ENGINEERING, INC.** FULLERTON, CA 92833 U.S.A.
TEST ENGINEER: S. COOK	4-25-12	LIGHTNING DIRECT EFFECTS TEST REPORT FOR THE
TEST DEPT. MGR: T. VU.	4/25/12	COMPOSITE PANELS (FORTY FOUR SAMPLES)
QUAL. ASSURANCE: M. NEIS	4/25/12	PREPARED FOR: CESSNA AIRCRAFT CORPORATION PURCHASE ORDER NUMBER: CEDO478326

SIZE	CAGE CODE	DRAWING NO.
A	63242	TR056893 / 20156
SCALE: NONE	REV LTR -	SHEET 1

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

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APPENDICES

LIGHTNING DIRECT EFFECTS TEST COMPLETION RECORD

For

CESSNA AIRCRAFT CORPORATION

COMPOSITE PANELS (FORTY FOUR SAMPLES)

Sample Numbers: LS-1 through LS-47

Test Start Date: 4-16-12 **Test Completion Date: 4-20-12**

Test Completion Record: The Composite Panels completed the High Current test in accordance with SAE ARP5416.

Lightning Direct Effects: The Customer will determine the Pass/Fail status of the test sample for this test.

DNB TEST ENGINEER ____________ DATE 4-25-12

DNB QUALITY ASSURANCE ____________ DNB 2 DATE 4/26/12

CUSTOMER TEST ENGINEER ____________ DATE ____________

SIZE	CAGE CODE	DRAWING NO.	
A	63242	TR056893	
SCALE: NONE		REV LTR -	SHEET 4

1.0 INTRODUCTION

Lightning Direct Effect tests for Category 2A were performed on forty four Composite Panels, manufactured by Cessna Aircraft Corporation. Testing began on 4-16-12 and was completed on 4-20-12. The purpose of this test was to demonstrate compliance with the applicable sections of SAE ARP5416. All test results have been summarized herein, and all data sheets have been incorporated in Appendix D.

2.0 TEST REQUIREMENTS

The test requirements for the tests performed as outlined in this document are defined by the applicable sections of SAE ARP5416.

3.0 TEST EQUIPMENT

The test equipment log in Appendix B lists information on test equipment used, along with current calibration status. DNB's calibration service providers use procedures provided by the manufacturers and by other widely recognized bodies (for example, GIDEP). Standards used during calibration are traceable to NIST.

4.0 SUMMARY OF TEST RESULTS

4.1 **Lightning Direct Effects**, SAE ARP5416

Introduction

Direct Effect Lightning tests for Category 2A were performed on the forty four Composite Panels which included High Current tests.

High Current Test

High Current calibration and tests were performed with the high current generator configured for negative polarity. The electrode was placed 50 mm above the Composite Panel. A leader wire was connected to the electrode and positioned just above the Composite Panel. An aluminum panel was used for the calibration. High current components D, B, and C* were then applied. This was done for the aluminum panel and the forty four Composite Panels. The following waveforms were applied to the Composite Panels:

Component D: I_P = 100 KA +/-10%; Action Integral = 2.5E5 A^2-S +/-20%
Component B: I_{avg}=2000 Amps +/-10%; Charge Transfer@5 mS=10 Coulombs +/-20%
Component C*: I_{avg} = 400 Amps +/-10%; Charge Transfer = 6 Coulombs +/-20%
Component A: I_P = 200 KA +/-10%; Action Integral = 2.0E6 A^2-S +/-20%

4.1 Lightning Direct Effects *(Continued)*

High Current Test

A metal strip was placed on the back side of the Composite Panel to simulate a wiring bundle or fuel line. This is done as a worst case setup to try and induce a puncture. The metal strip was connected to ground with a 30 awg fuse wire. After each strike, the wire was checked to see if there was enough current coupled to the metal strip to open the fuse wire. After the completion of the forty four panels, three panels were selected for a Zone 1A strike and were tested with Components A, B, and C*.

Pre and Post Functional Test Data

If applicable, the Composite Panels were checked for proper functionality prior to the direct effects lightning tests. After completion of the direct effects lightning tests, the Composite Panels were again checked for proper functionality. Any available pre and post functionality data is provided in a separate Cessna Aircraft Corporation document.

4.1 Lightning Direct Effects *(Continued)*

Test Results

The Composite Panels showed varying degrees of damage. None of the Composite Panels showed any signs of puncture. One Composite Panel that was struck resulted in the fuse wire opening. This was panel LS-19.

Test Log

The Test Log is provided in Appendix A.

Test Equipment

A list of the test equipment used to perform all testing complete with calibration dates is provided in Appendix B.

Test Data

Test Data are provided in Appendix D.

Test Photographs

Test photographs are provided in Appendix E.

Disposition of Test Samples

Following testing, the Composite Panels were returned to Cessna Aircraft Corporation for further evaluation.

Bonding Measurements

Bonding measurements were not performed during these tests.

5.0 TEST DESCRIPTION

The test method and description, including details of the test set-up and test figures are described in SAE Arp5416 for each of the lightning tests. A list of the test equipment used in the performance of each of these tests, along with current calibration information is included in Appendix B. Photographs of each test setup were taken and are included in Appendix E.

6.0 CONCLUSIONS

The Composite Panels completed the direct effects lightning tests in accordance with SAE ARP5416. Upon the completion of testing, the test sample and all applicable Cessna Aircraft Corporation support equipment were returned to representatives of Cessna Aircraft Corporation.

The results listed in this report relate only to the items tested as listed on the Test Completion Record on sheet 4 herein.

APPENDIX A

Test Log

SIZE	CAGE CODE	DRAWING NO.
A	63242	TR056893
SCALE: NONE	REV LTR -	SHEET A1

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

LIGHTNING TEST LOG

CUSTOMER: CESSNA	TEST SAMPLE: PANELS
TEST ENGINEER: STEVE COOK	CUSTOMER REP: BILLY MARTIN

DATE	TIME	TEST DESCRIPTION
4-18-12	10:50	LS-19 – Zone 2A 30 awg fuse opened
	11:30	LS-15 – Zone 2A
	11:55	LS-11 – Zone 2A
	2:05	LS-12 – Zone 2A
	2:30	LS-14 – Zone 2A
	2:55	LS-27 – Zone 2A
	3:20	LS-37 – Zone 2A
	3:45	LS-41 – Zone 2A
	4:05	LS-25 – Zone 2A
	4:30	LS-46 Side 1 – Zone 2A
	5:20	LS-42 – Zone 2A
	6:00	End testing for 4-18-12.
4-19-12	8:00	Continue high current test.
	8:20	LS-8 – Zone 2A
	8:40	LS-43 – Zone 2A
	9:05	LS-38 – Zone 2A
	9:25	LS-5 – Zone 2A
	9:45	LS-18 – Zone 2A
	10:10	LS-26 – Zone 2A
	10:35	LS-7 – Zone 2A
	11:05	LS-28 – Zone 2A
	11:30	LS-47 – Zone 2A
	2:10	LS-9 – Zone 2A
	2:30	LS-24 – Zone 2A
	3:00	LS-10 – Zone 2A
	3:25	LS-23 – Zone 2A
	4:10	LS-34 – Zone 1A
	4:45	LS-40 – Zone 1A

LIGHTNING TEST LOG

CUSTOMER: CESSNA	TEST SAMPLE: PANELS
TEST ENGINEER: STEVE COOK	CUSTOMER REP: BILLY MARTIN

DATE	TIME	TEST DESCRIPTION
4-19-12	5:00	End testing for 4-19-12.
4-20-12	8:00	Continue high current testing.
	8:55	Panel LS-39 – Zone 1A
	10:00	Testing completed.

APPENDIX B

Test Equipment Log

SIZE	CAGE CODE	DRAWING NO.	
A	63242	TR056893	
SCALE: NONE		REV LTR -	SHEET B1

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

TEST EQUIPMENT LOG

DIRECT EFFECT LIGHTNING

MANUFACTURER	DESCRIPTION	MODEL NO.	SERIAL NO.	CAL DUE
DNB	COMPONENT A/D	100KV200KA	001	CPT
DNB	COMPONENT B GENERATOR	15KV2160	001	CPT
DNB	COMPONENT C GENERATOR	72900VDC	001	CPT
PEARSON	CURRENT PROBE – A/D	1423	2343	11-30-12
PEARSON	CURRENT PROBE – B	301X	1212	10-24-12
DNB	CURRENT PROBE – C	HMHB100	12364	12-14-13
YOKOGAWA	SCOPECORDER	DL750	12B07030H	1-16-14
BIRD	20 dB ATTENUATOR	150-SA-FFN-20	162467	8-31-12
BIRD	20 dB ATTENUATOR	150-SA-FFN-20	0219	8-31-12

CPT – Calibration performed prior to test.

APPENDIX C

Transducer Factors

N/A

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

APPENDIX D

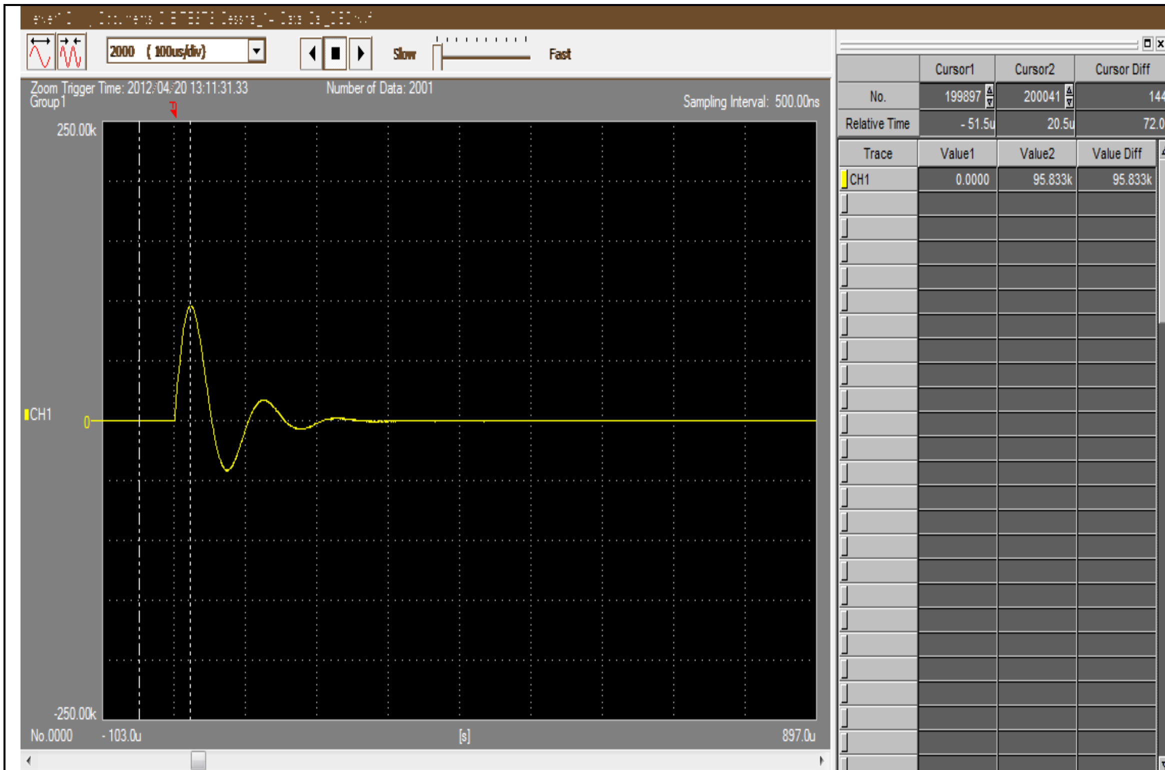
Test Data

DIRECT EFFECT LIGHTNING TEST SUMMARY

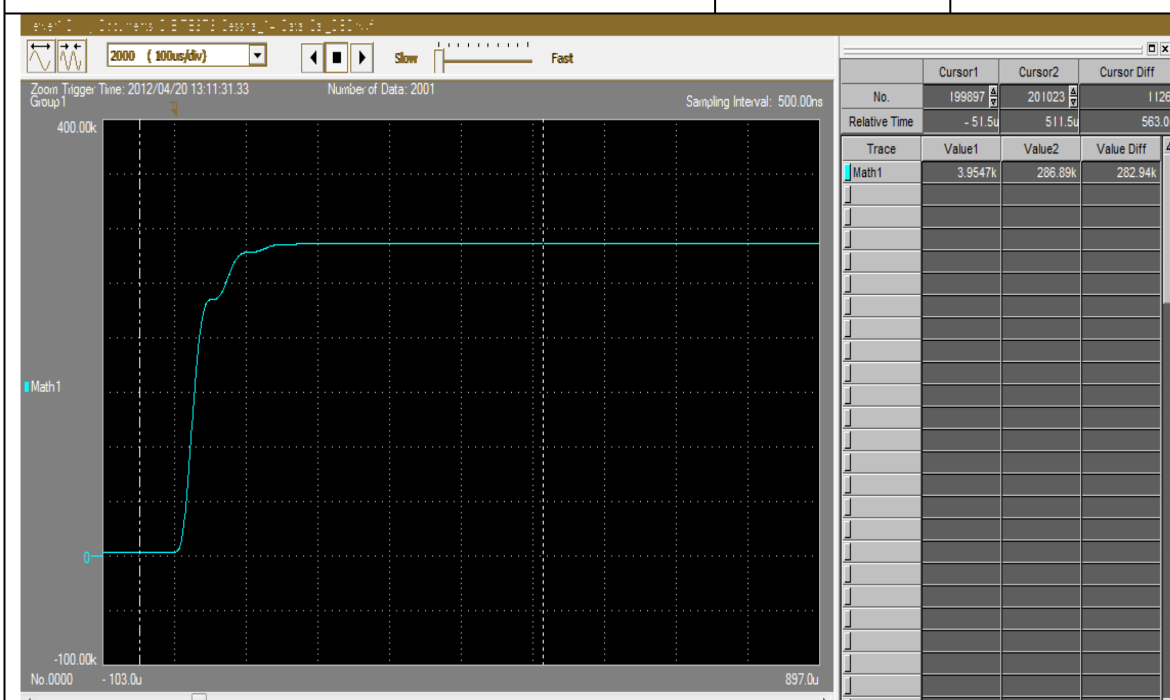
Test Panel	Comp. A/D Ip (KA)	Comp. A/D AI (A^2S)	Comp. B Iavg (Amps)	Comp. B CT (C)	Comp. C* Ip (Amps)	Comp. C* CT (C)
Cal	95.8	282940	2192	10.958	394	4.0
LS-1	94.3	269300	2310	11.552	345	5.2
LS-2	93.7	266070	2268	11.338	306	2.2
LS-4	92.8	254970	2192	10.960	223	1.1
LS-5	95.2	273070	2116	10.579	84	0.2
LS-6-1	92.5	262390	2197	10.985	281	0.82
LS-6-2	91.8	249880	2252	11.260	261	5.9
LS-7	95.2	275000	2213	11.064	303	5.6
LS-8	94.8	270680	2189	10.947	301	5.4
LS-9	92.5	238070	2234	11.171	288	5.1
LS-10	95.7	276650	2082	10.408	146	0.17
LS-11	94.7	262030	2051	10.256	242	3.7
LS-12	95.0	269070	2266	11.329	283	6.0
LS-13	92.7	256770	2163	10.814	365	12.3
LS-14	95.0	273060	2174	10.872	354	4.4
LS-15	95.5	273200	2295	11.475	358	4.3
LS-16	95.2	271810	2343	11.713	325	5.3
LS-18	94.2	269380	2154	10.768	225	5.4
LS-19	95.2	270740	2246	11.228	267	5.9
LS-20-1	90.5	247740	2152	10.761	297	16.6
LS-20-2	99.7	297860	2014	10.068	243	0.66
LS-21	93.7	267580	2168	10.840	367	4.3
LS-22	94.5	270350	2220	11.099	289	5.9
LS-23	95.8	277130	2332	11.662	230	3.2
LS-24	95.2	275240	2235	11.174	264	6.4
LS-25	94.3	267390	2223	11.117	317	4.3
LS-26	95.5	275530	2091	10.454	294	6.1
LS-27	94.0	262530	2094	10.468	270	6.5
LS-28	93.0	259950	2203	11.013	327	5.3
LS-29	94.0	271020	2287	11.437	297	5.3
LS-30	94.0	266340	2218	11.092	330	5.1
LS-32	91.8	251710	2133	10.666	329	4.7

DIRECT EFFECT LIGHTNING TEST SUMMARY

Test Panel	Comp. A/D Ip (KA)	Comp. A/D AI (A^2S)	Comp. B Iavg (Amps)	Comp. B CT (C)	Comp. C Ip (Amps)	Comp. C* CT (C)
LS-33	93.7	267780	2221	11.105	258	6.7
LS-34	91.3	249210	2224	11.120	277	2.9
LS-35	94..0	268530	2079	10.397	299	6.1
LS-36	94.0	267970	2150	10.752	305	5.6
LS-37	93.3	253830	2178	10.890	183	0.70
LS-38	94.8	270310	2177	10.887	343	4.9
LS-39	92.2	251850	2257	11.283	293	6.0
LS-40	92.8	263700	2140	10.698	253	1.3
LS-41	93.7	260300	2285	11.426	239	5.4
LS-42	93.7	262790	2300	11.498	296	5.8
LS-43	94.2	262250	2136	10.681	181	0.54
LS-44	93.3	262610	2150	10.751	317	5.0
LS-45	90.8	253010	2046	10.230	6.0	0.009
LS-46	68.5	132140	2099	10.494	0	0
LS-47	70.7	140320	1829	9.146	1.3	0.004
LS-34	182.5	1.4532E6	2328	11.642	353	1.8
LS-39	175.0	1.4158E6	2150	10.750	267	1.1
LS-40	187.7	1.8343E6	2267	11.335	342	5.5

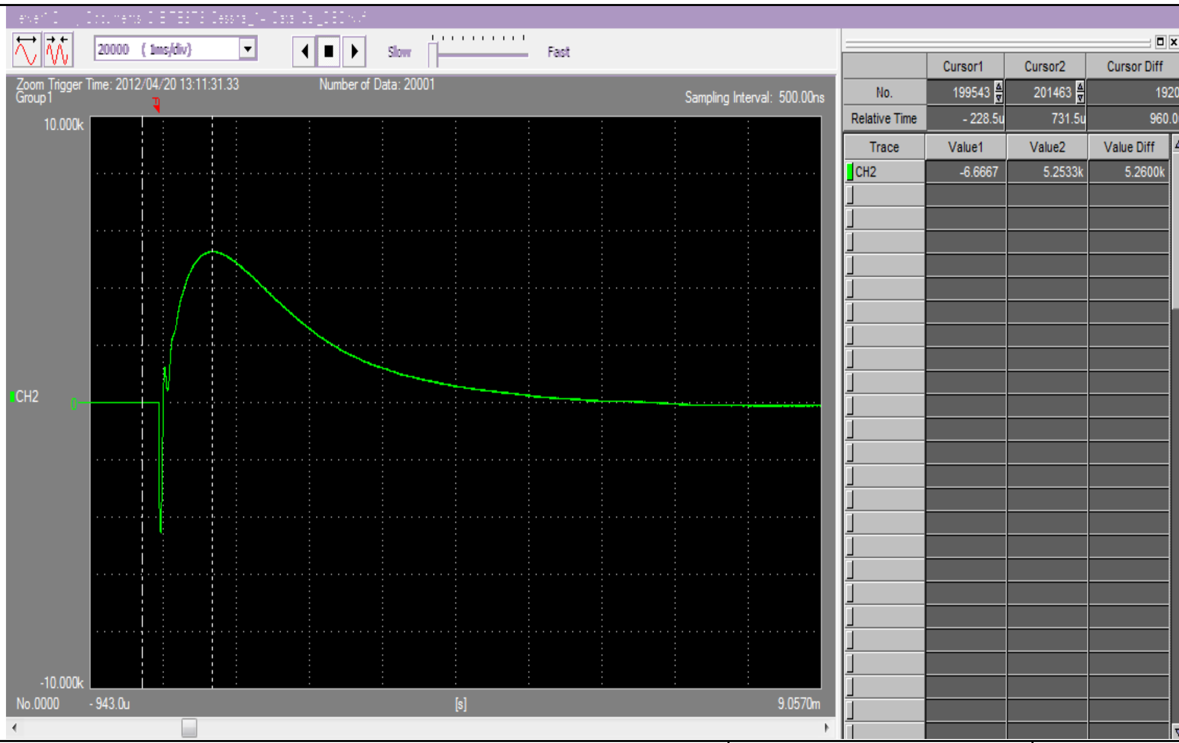


HIGH CURRENT – COMPONENT D	Ip = 95.8 KA	100 uS / Div

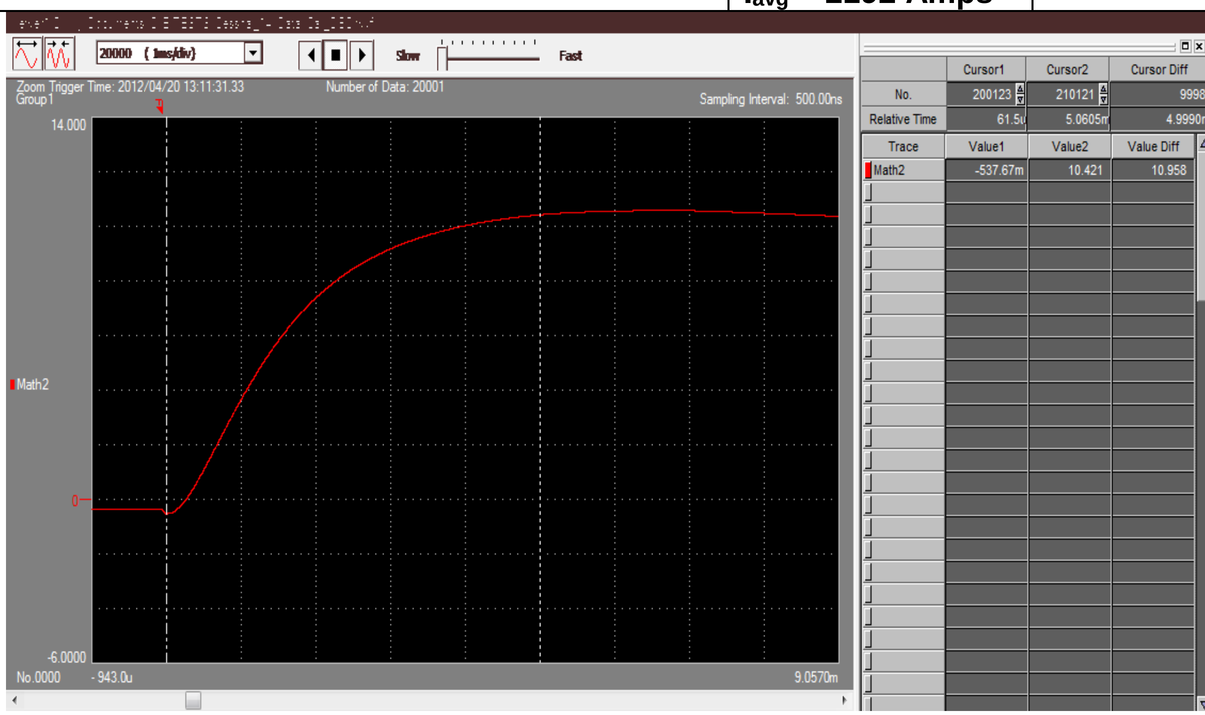


COMPONENT D ACTION INTEGRAL	AI = 282940 A^2-S

CALIBRATION

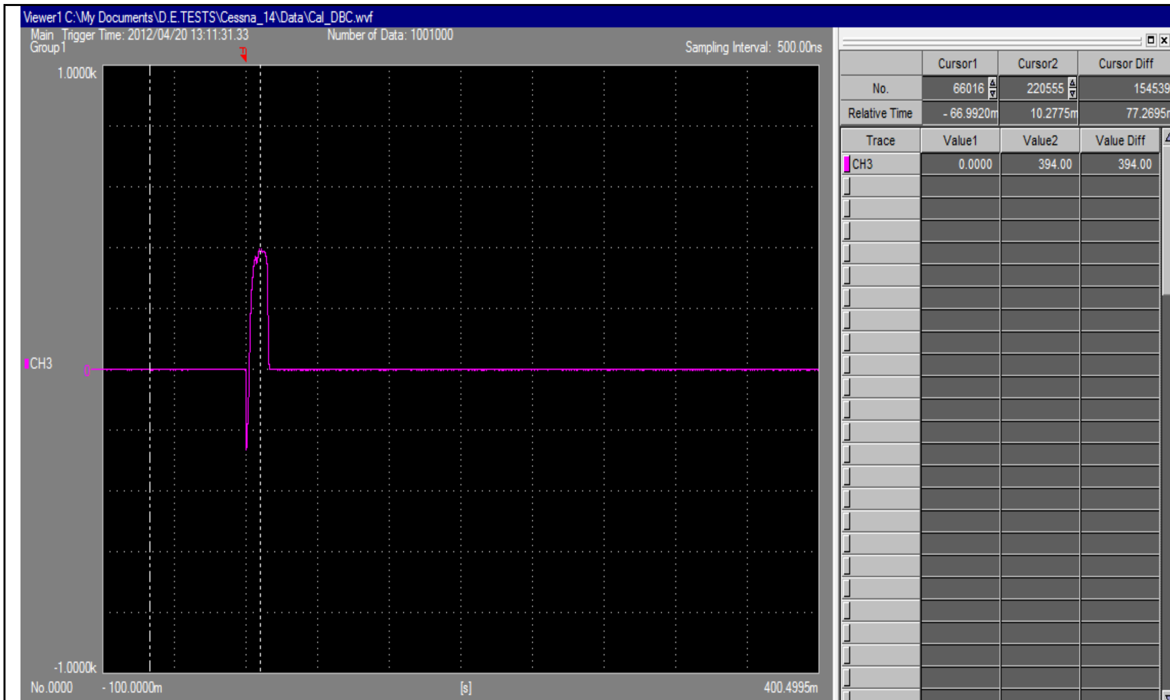


HIGH CURRENT – COMPONENT B	I_P = 5260 Amps I_{avg} = 2192 Amps	1 mS / Div

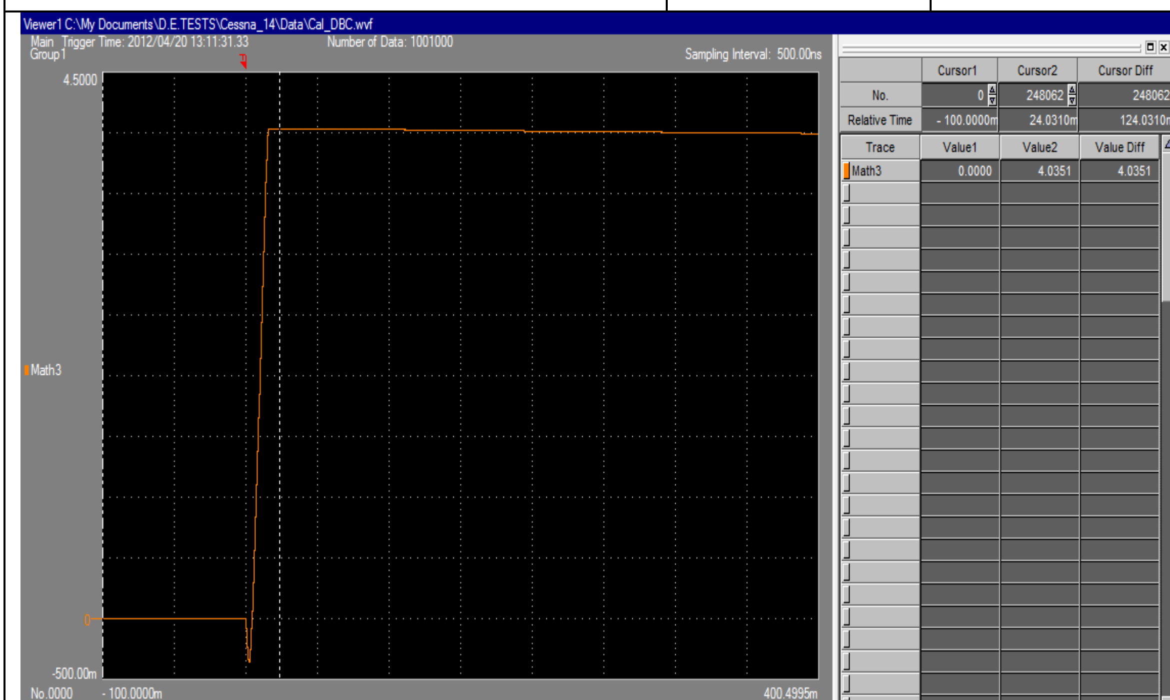


COMPONENT B CHARGE TRANSFER	10.958 Coulombs

CALIBRATION

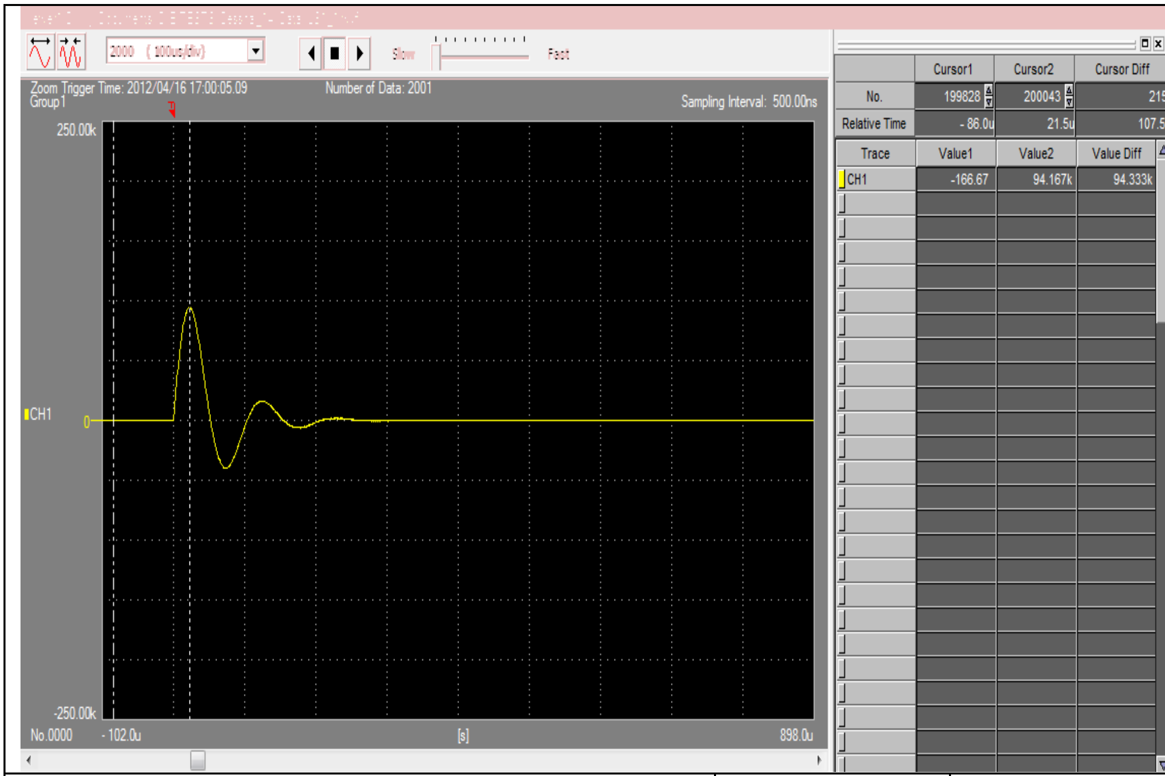


HIGH CURRENT – COMPONENT C*	Ip = 394 Amps	50 mS / Div

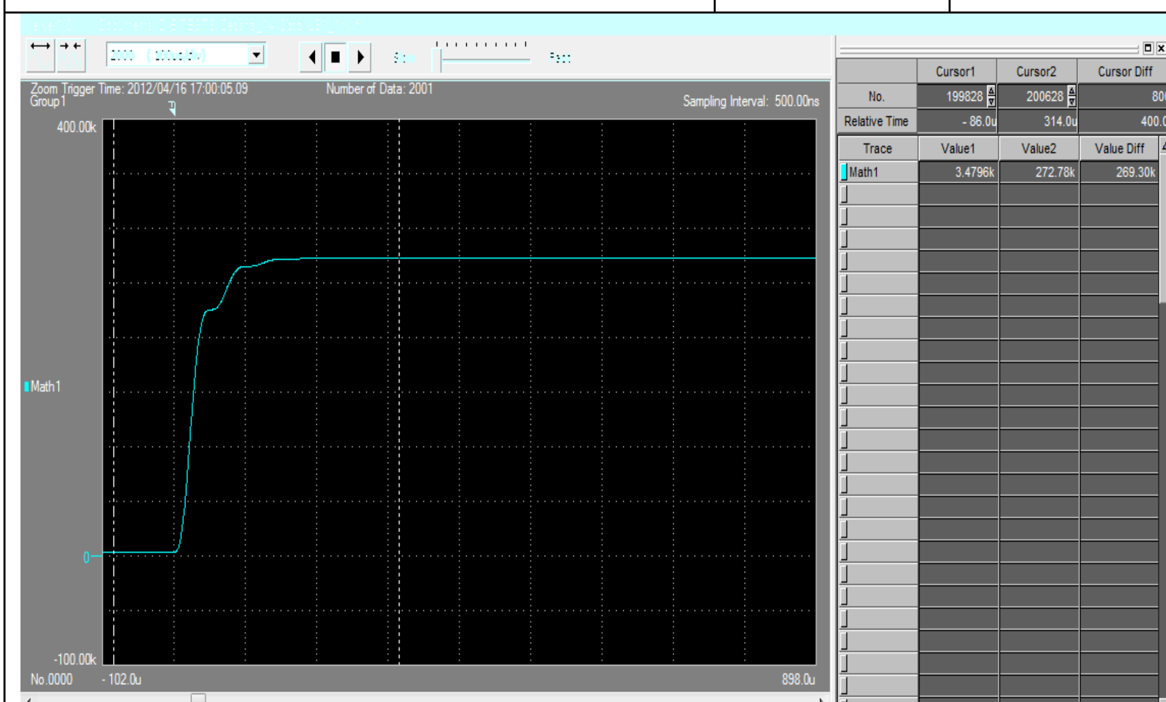


COMPONENT C* CHARGE TRANSFER	4.0 Coulombs

CALIBRATION

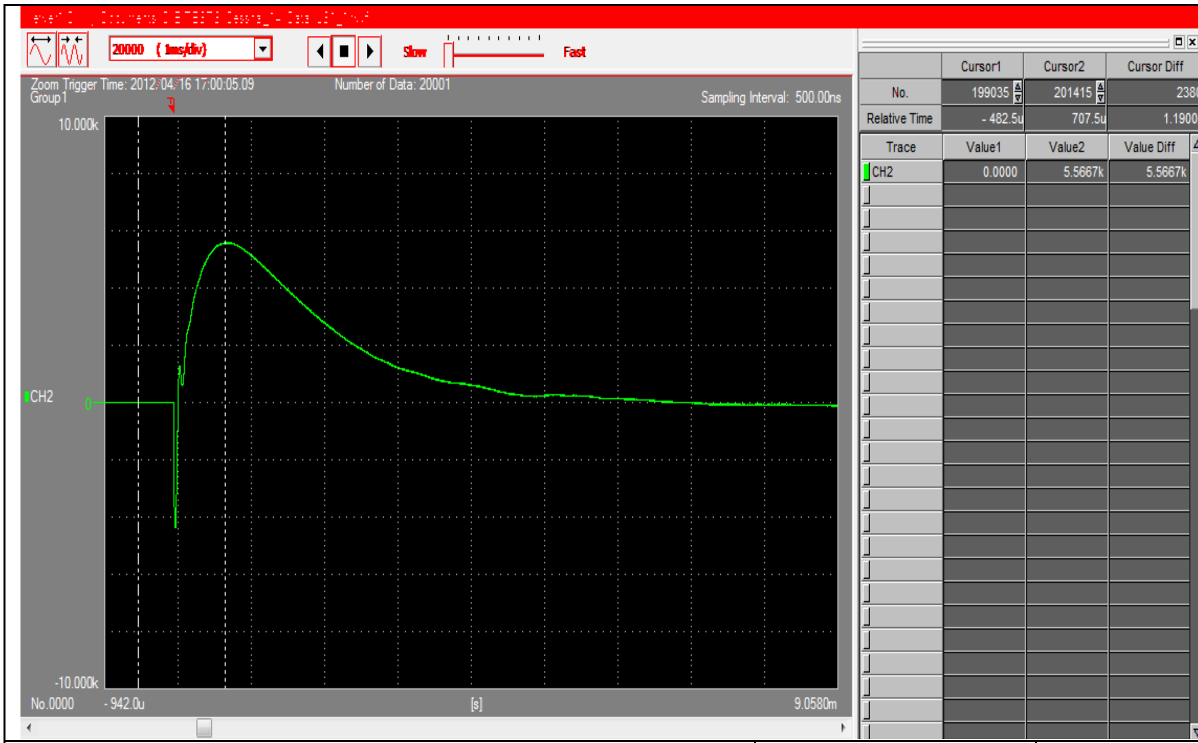


HIGH CURRENT – COMPONENT D	Ip = 94.3 KA	100 uS / Div

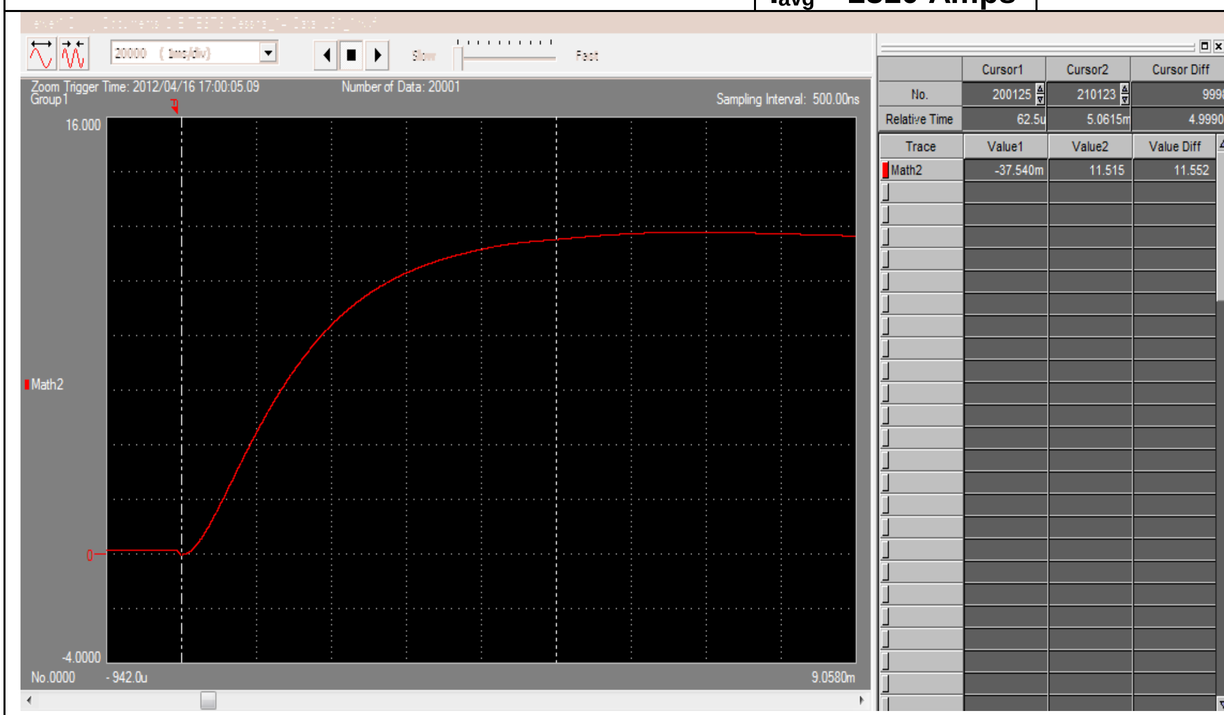


COMPONENT D ACTION INTEGRAL	AI = 269300 A^2-S

PANEL: LS-1

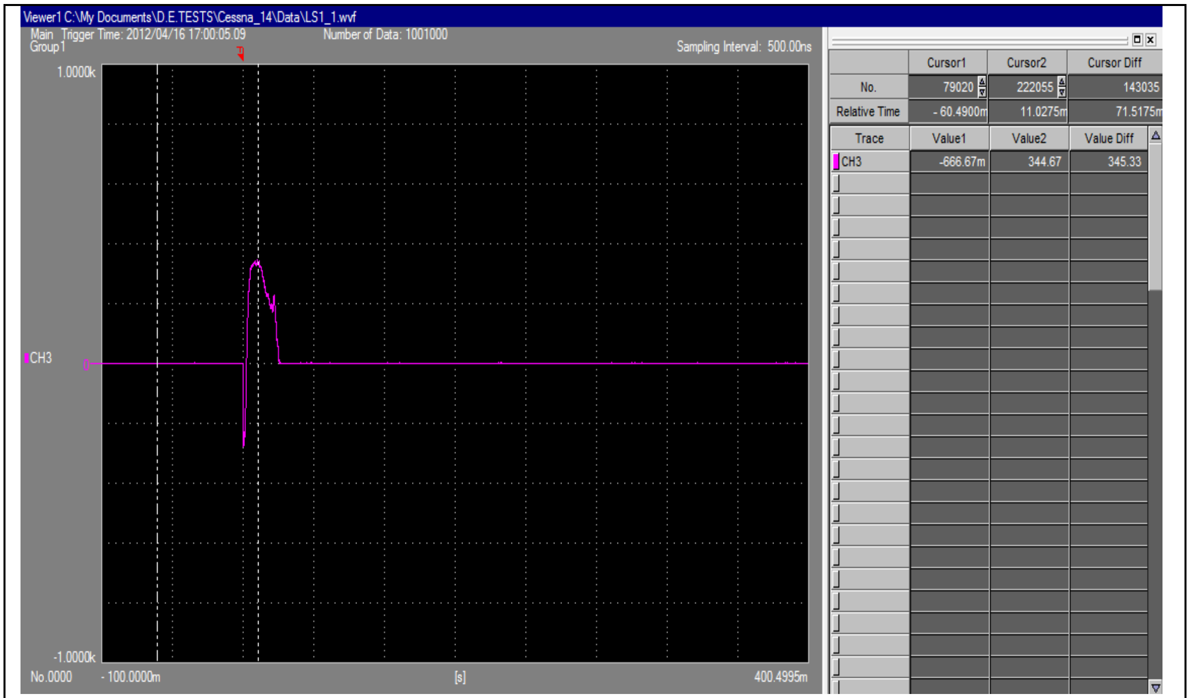


HIGH CURRENT – COMPONENT B	I_P = 5567 Amps I_{avg} = 2310 Amps	1 mS / Div

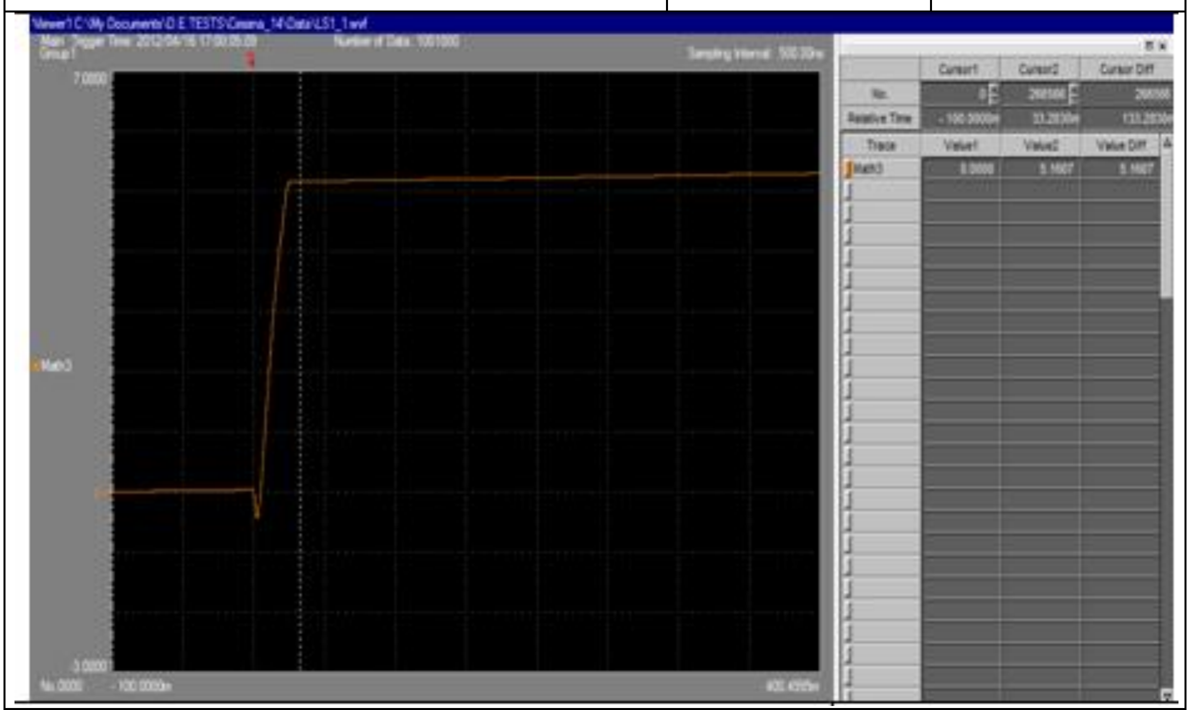


COMPONENT B CHARGE TRANSFER	11.552 Coulombs

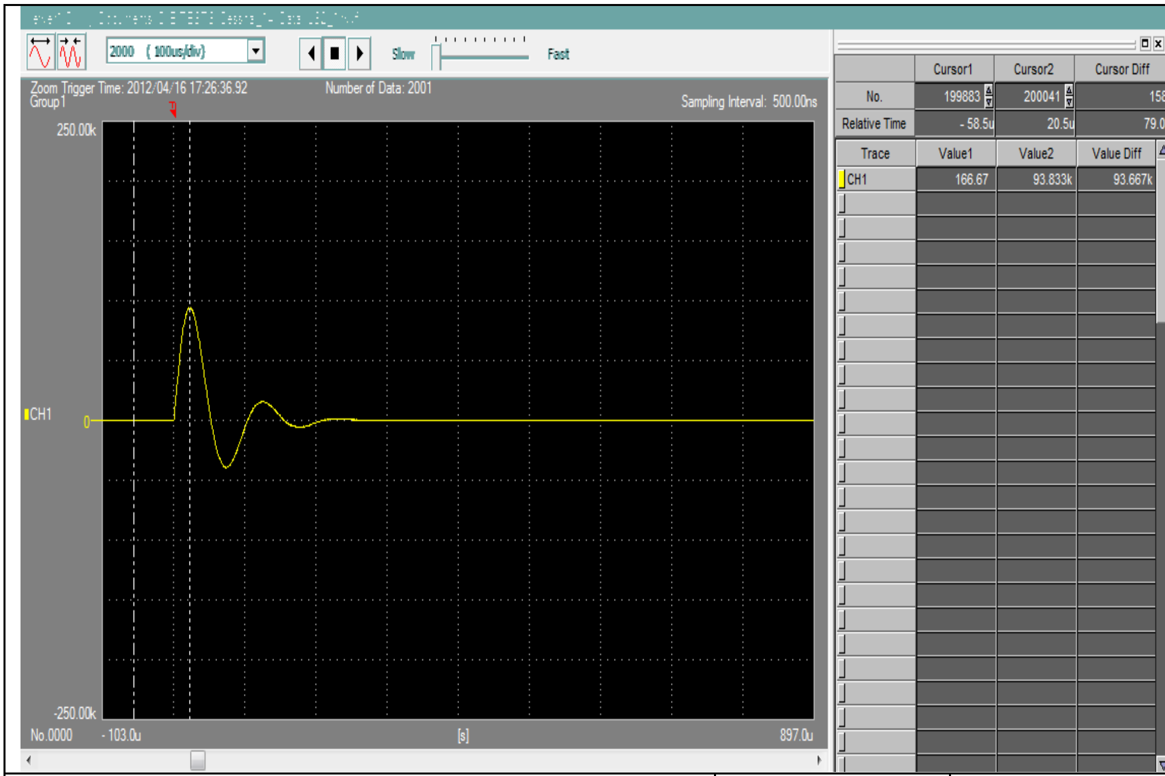
PANEL: LS-1



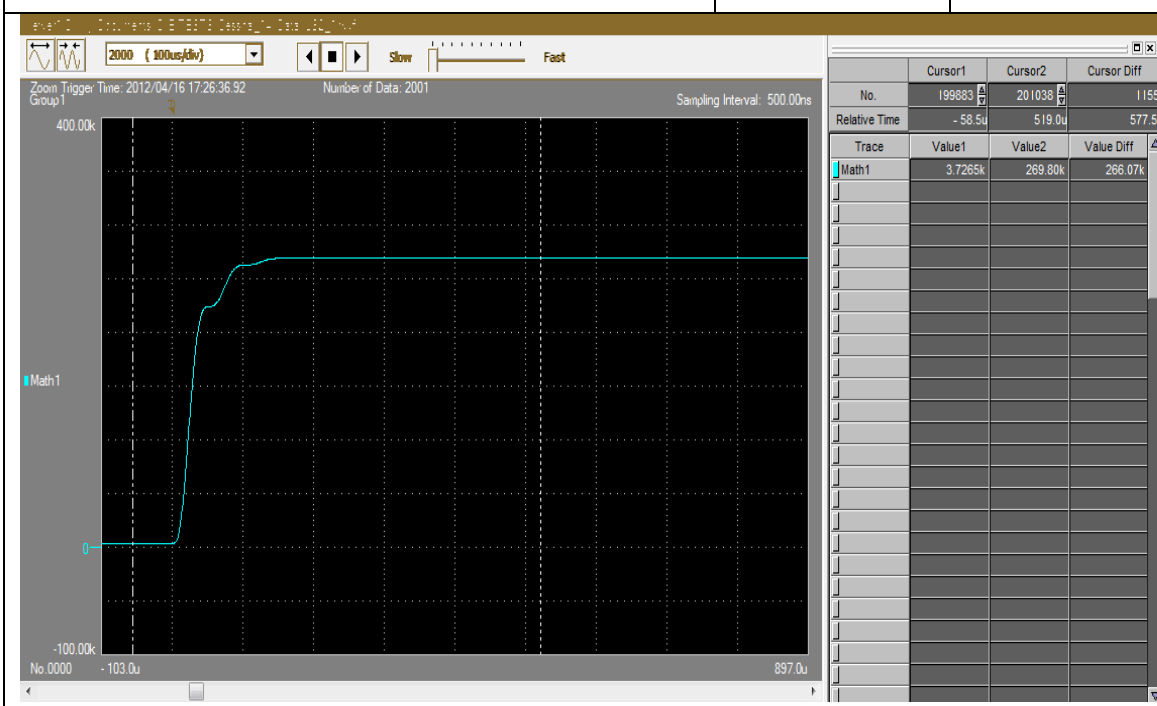
HIGH CURRENT – COMPONENT C*	Ip = 345 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	5.2 Coulombs
PANEL: LS-1	

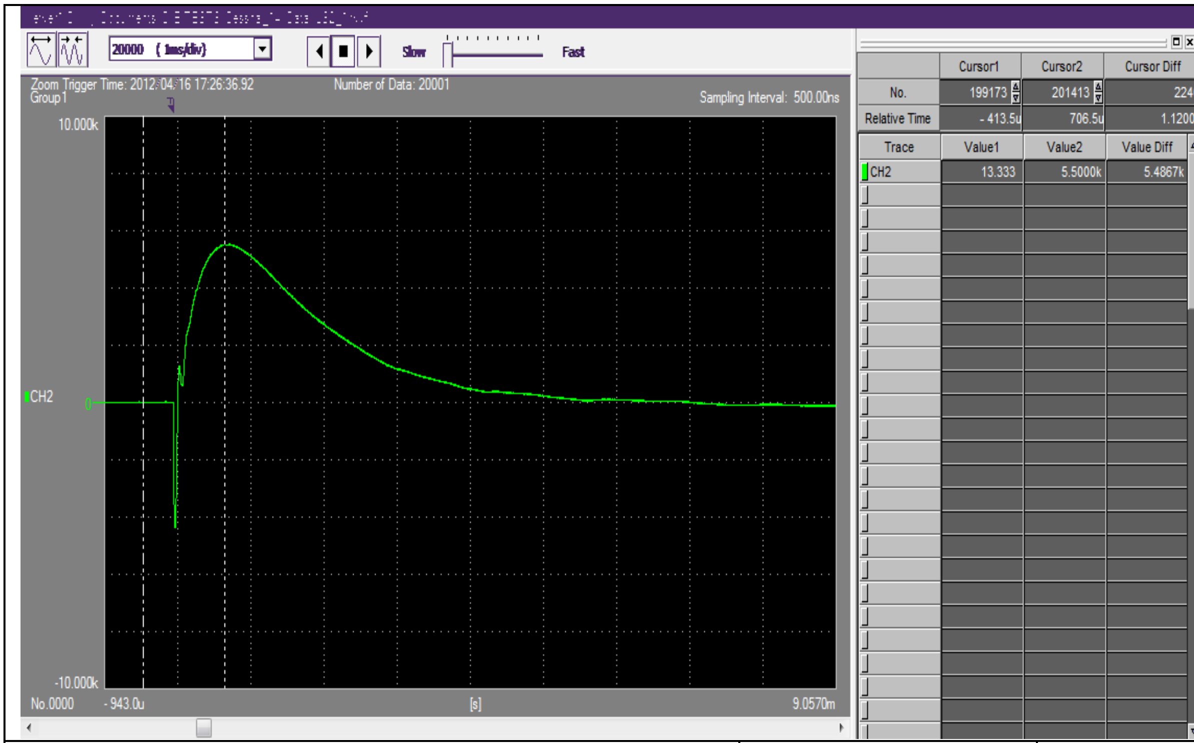


HIGH CURRENT – COMPONENT D	Ip = 93.7 KA	100 uS / Div

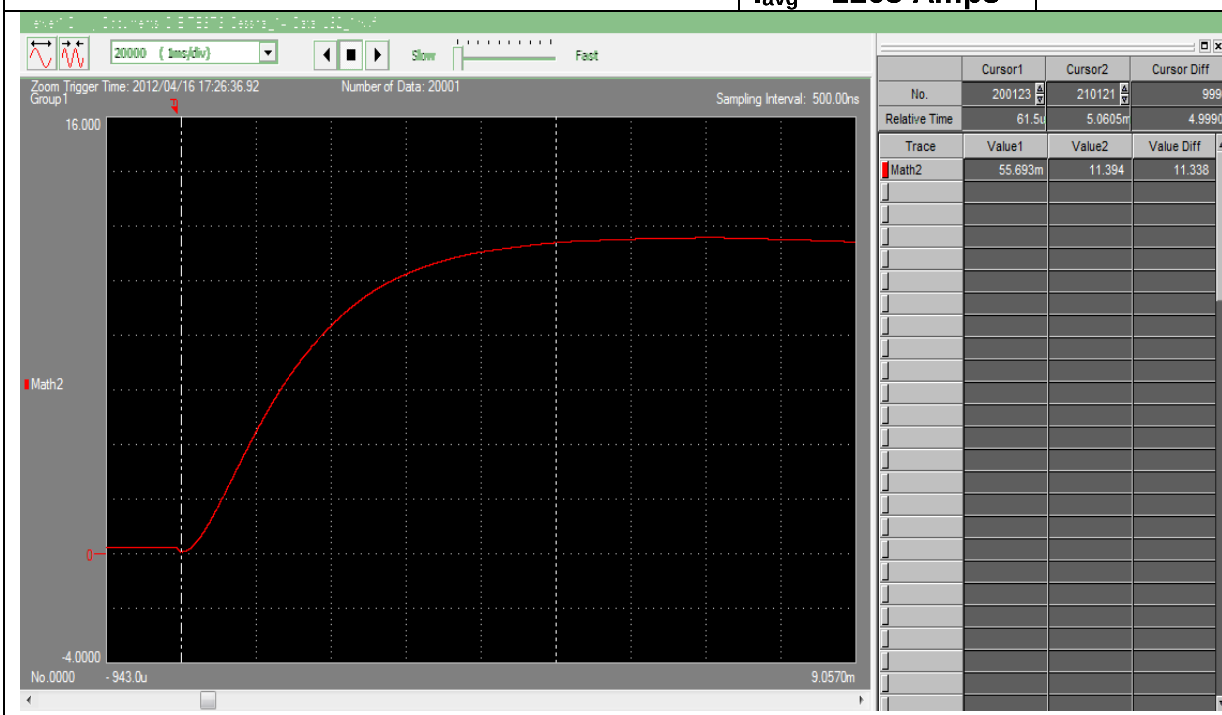


COMPONENT D ACTION INTEGRAL	AI = 266070 A^2-S

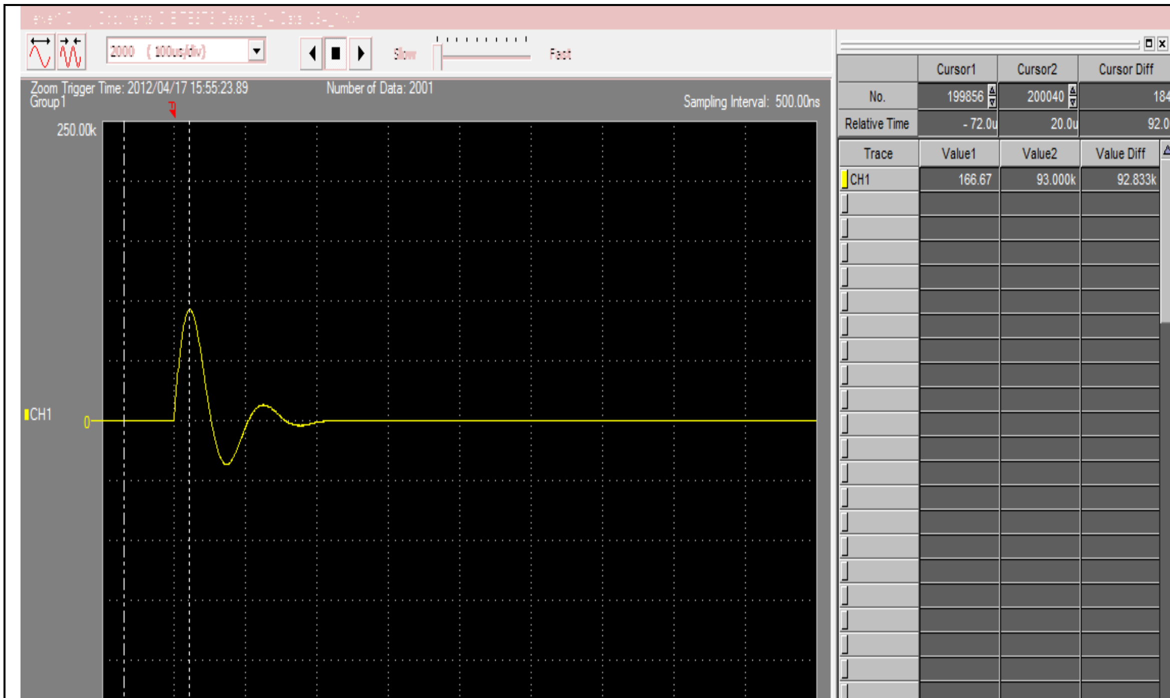
PANEL: LS-2



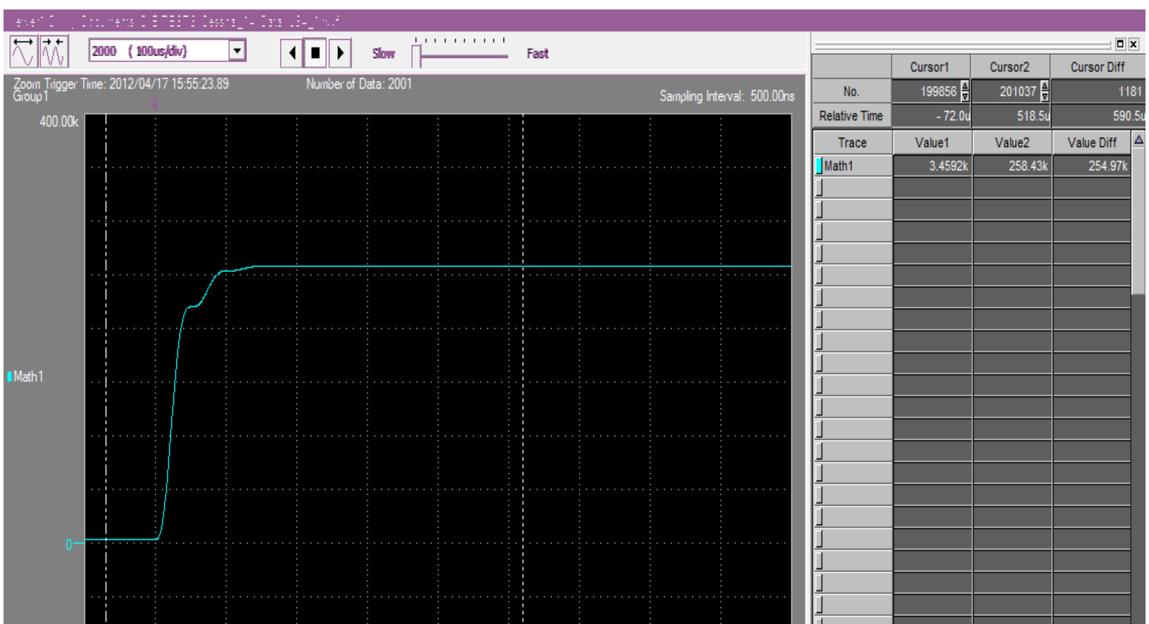
HIGH CURRENT – COMPONENT B	**I_P = 5487 Amps** **I_{avg} = 2268 Amps**	**1 mS / Div**



COMPONENT B CHARGE TRANSFER	**11.338 Coulombs**
PANEL: LS-2	

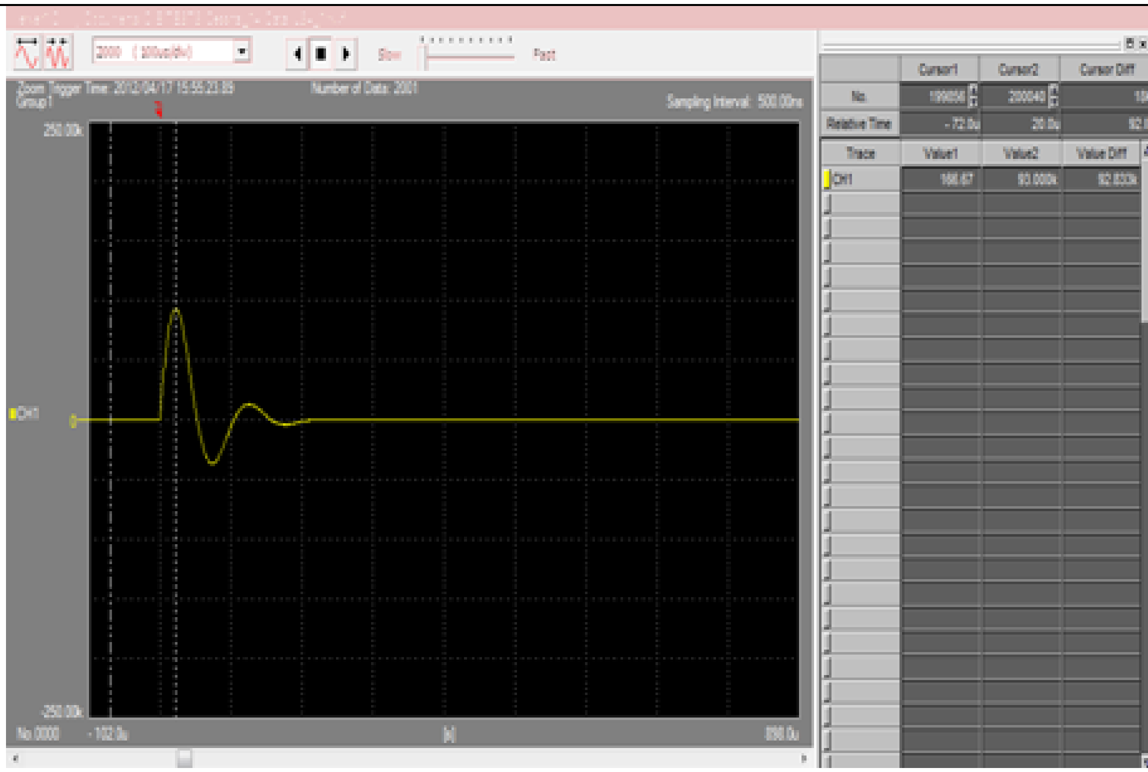


HIGH CURRENT – COMPONENT C*	Ip = 306 Amps	50 mS / Div

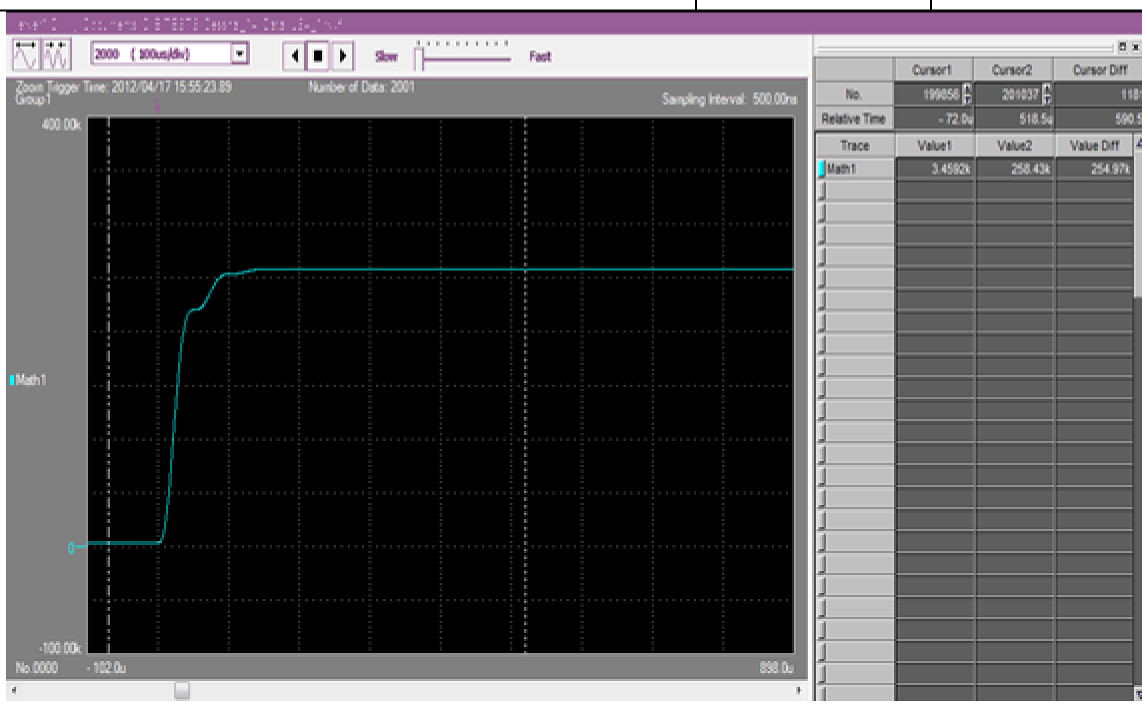


COMPONENT C* CHARGE TRANSFER	2.2 Coulombs

PANEL: LS-2

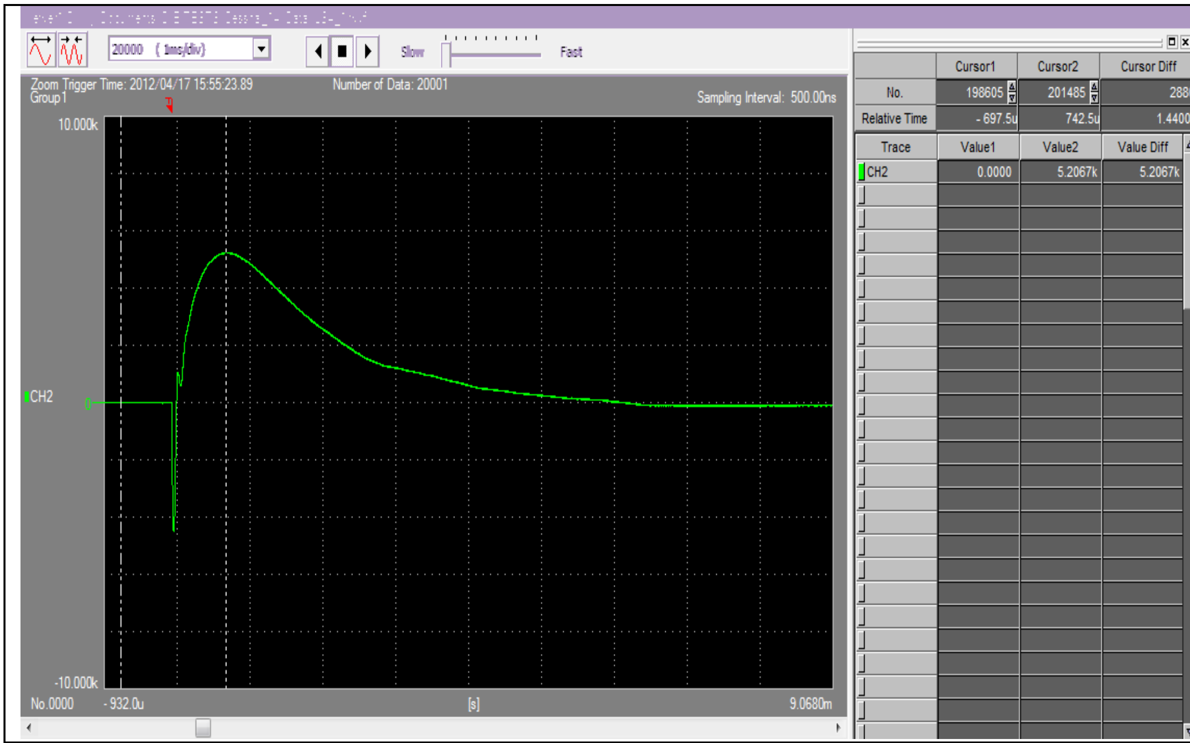


HIGH CURRENT – COMPONENT D	Ip = 92.8 KA	100 uS / Div

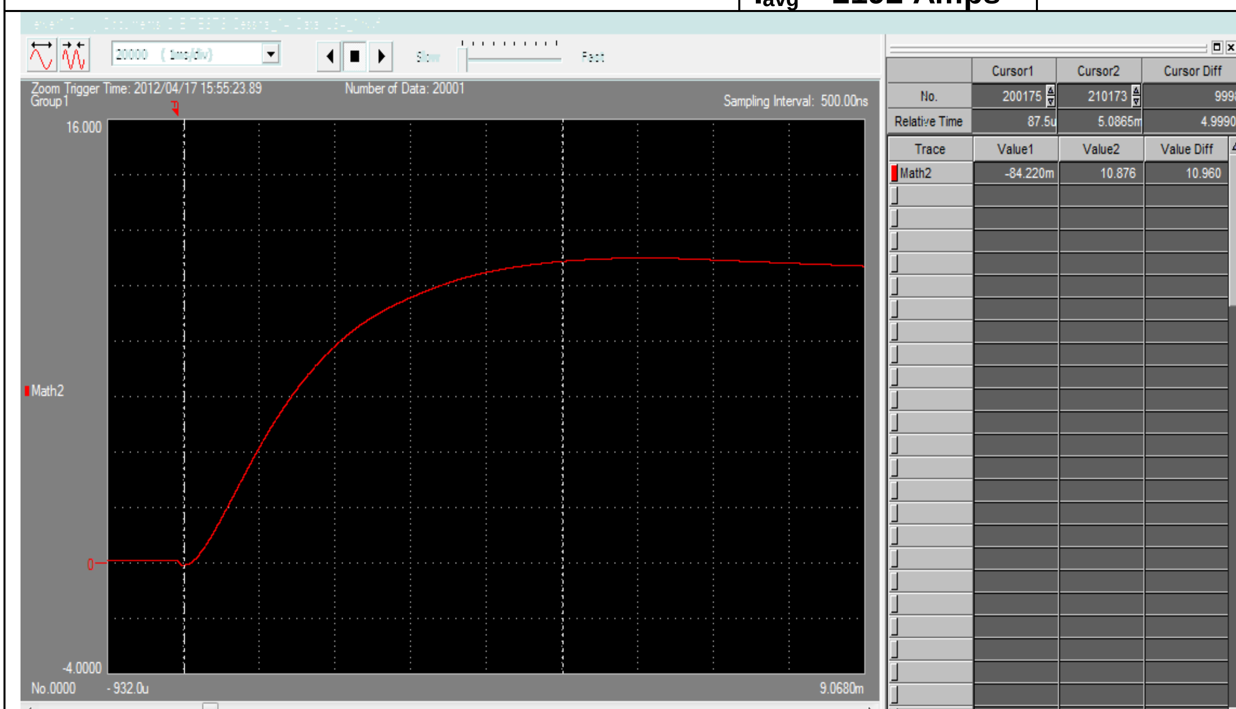


COMPONENT D ACTION INTEGRAL	AI = 254970 A^2-S

PANEL: LS-4

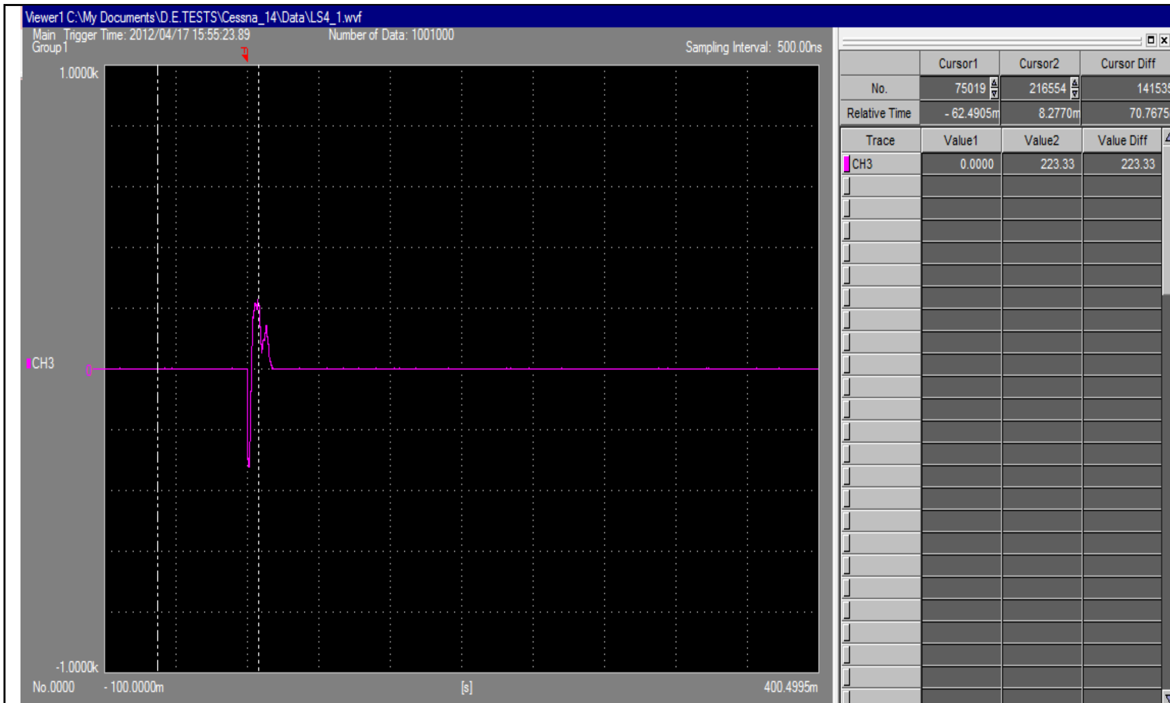


HIGH CURRENT – COMPONENT B	I_P = 5207 Amps I_{avg} = 2192 Amps	1 mS / Div

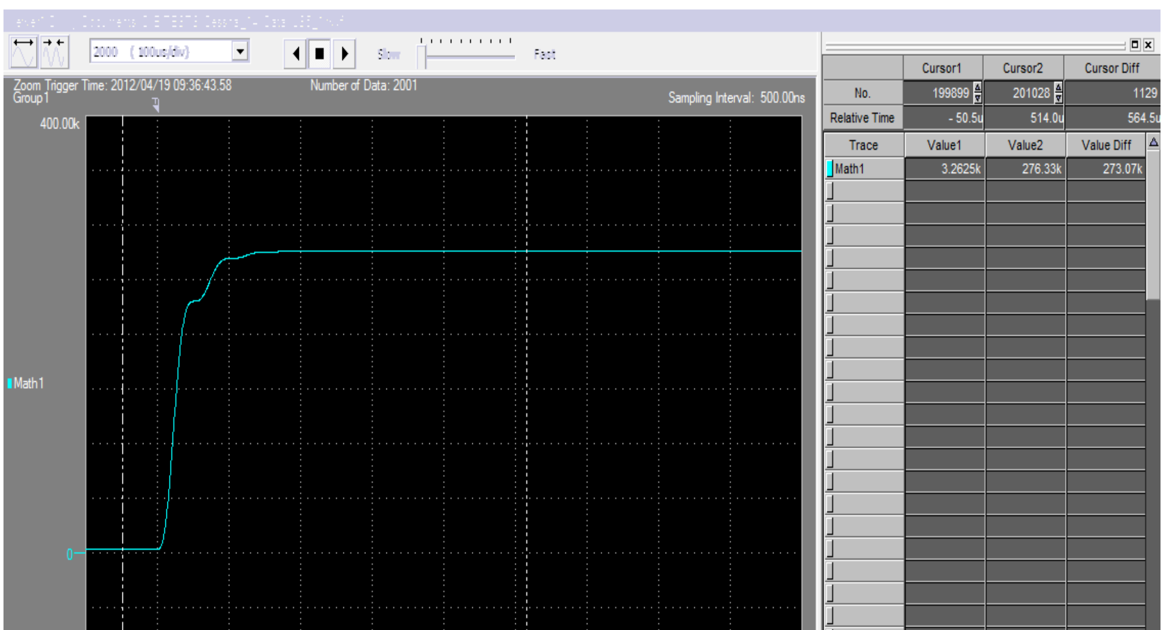


COMPONENT B CHARGE TRANSFER	10.960 Coulombs

PANEL: LS-4

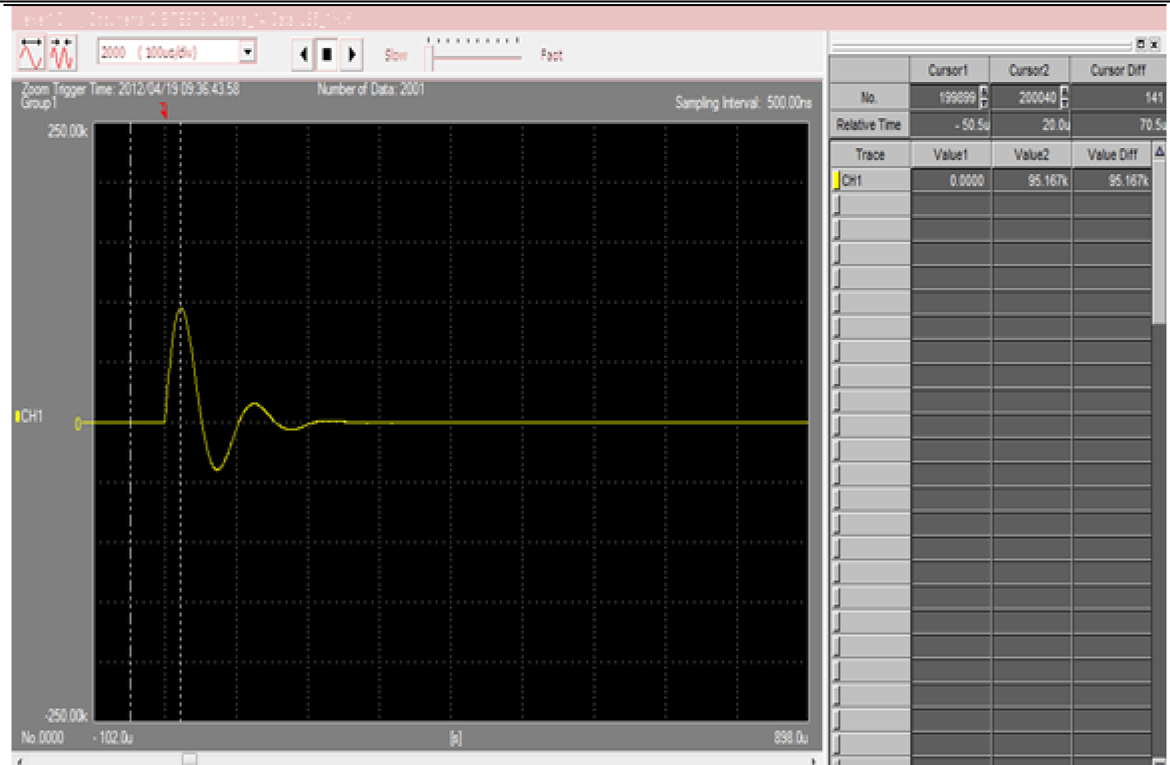


HIGH CURRENT – COMPONENT C*	Ip = 223 Amps	50 mS / Div

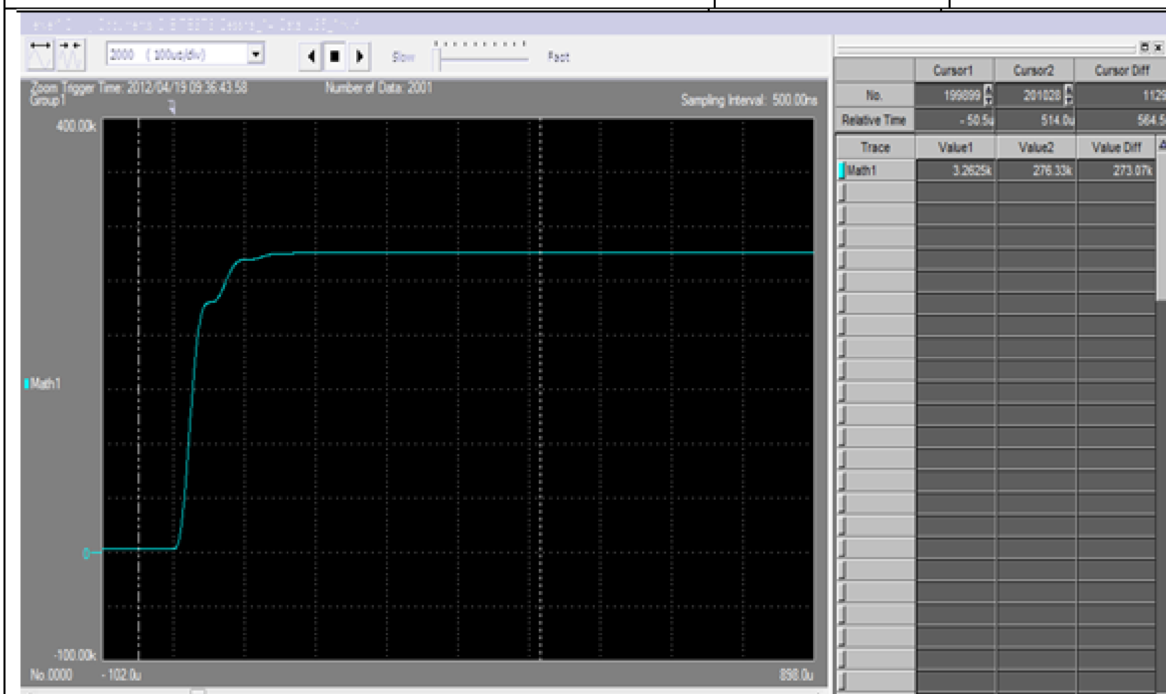


COMPONENT C* CHARGE TRANSFER	1.1 Coulombs

PANEL: LS-4

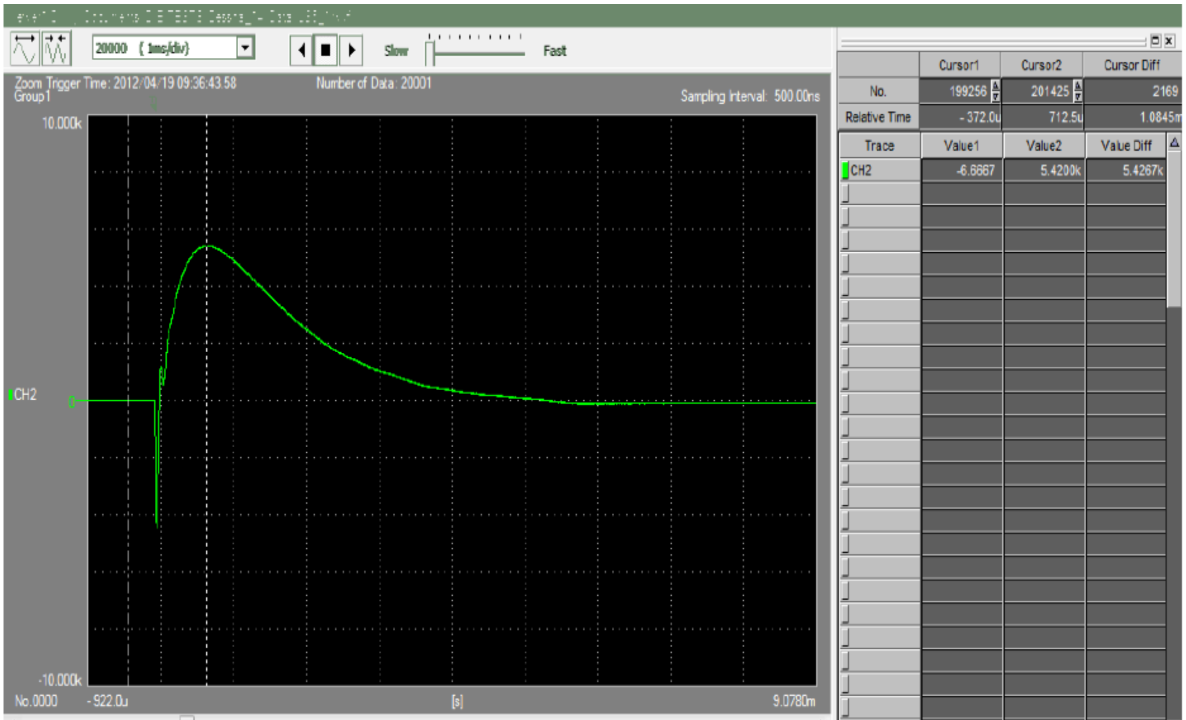


HIGH CURRENT – COMPONENT D	Ip = 95.2 KA	100 uS / Div

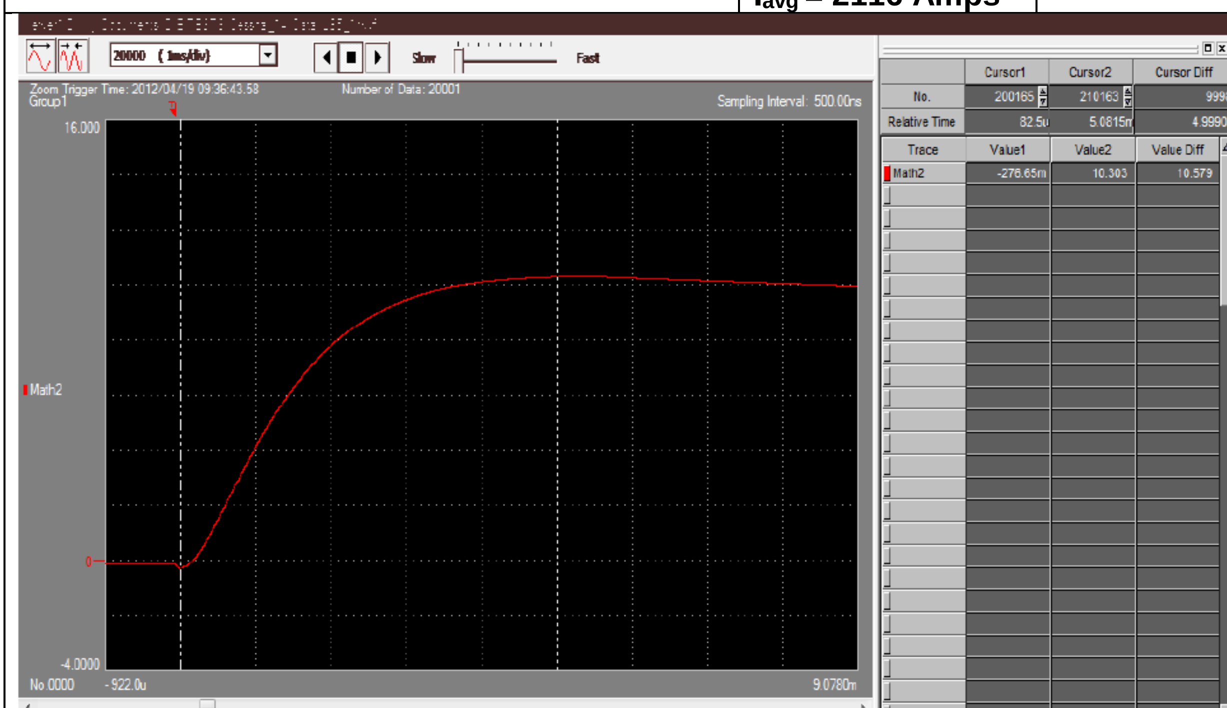


COMPONENT D ACTION INTEGRAL	AI = 273070 A^2-S

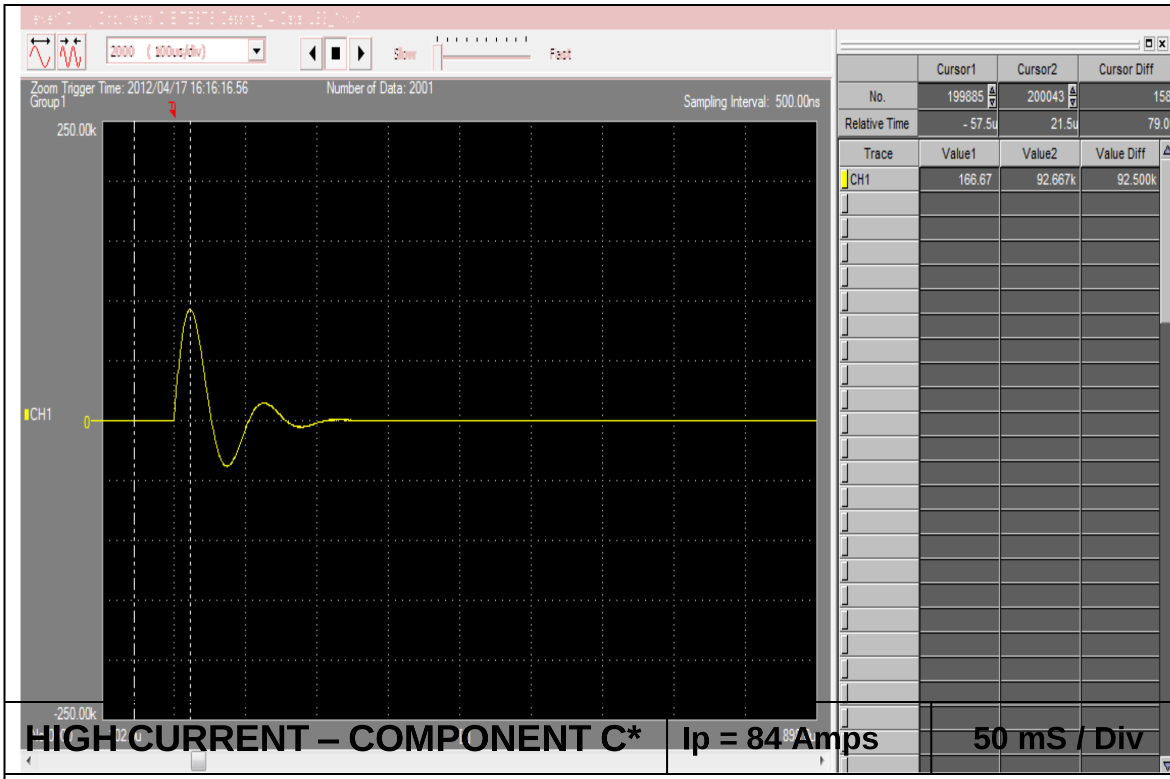
PANEL: LS-5



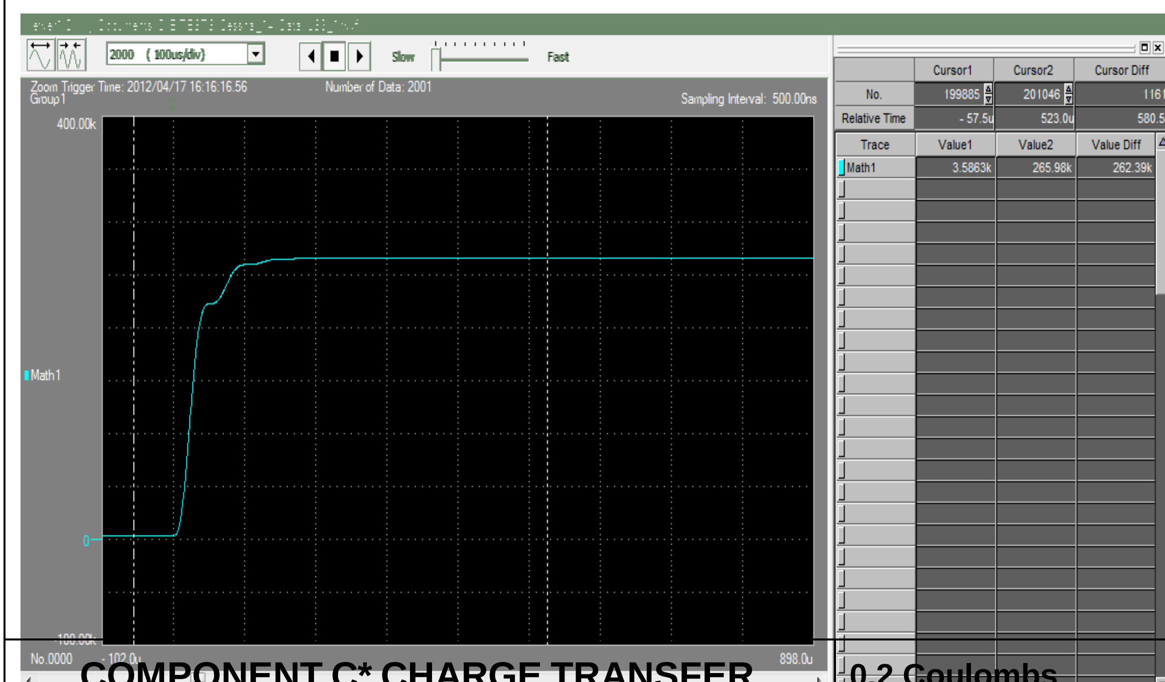
HIGH CURRENT – COMPONENT B	I_P = 5427 Amps I_{avg} = 2116 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.579 Coulombs
PANEL: LS-5	

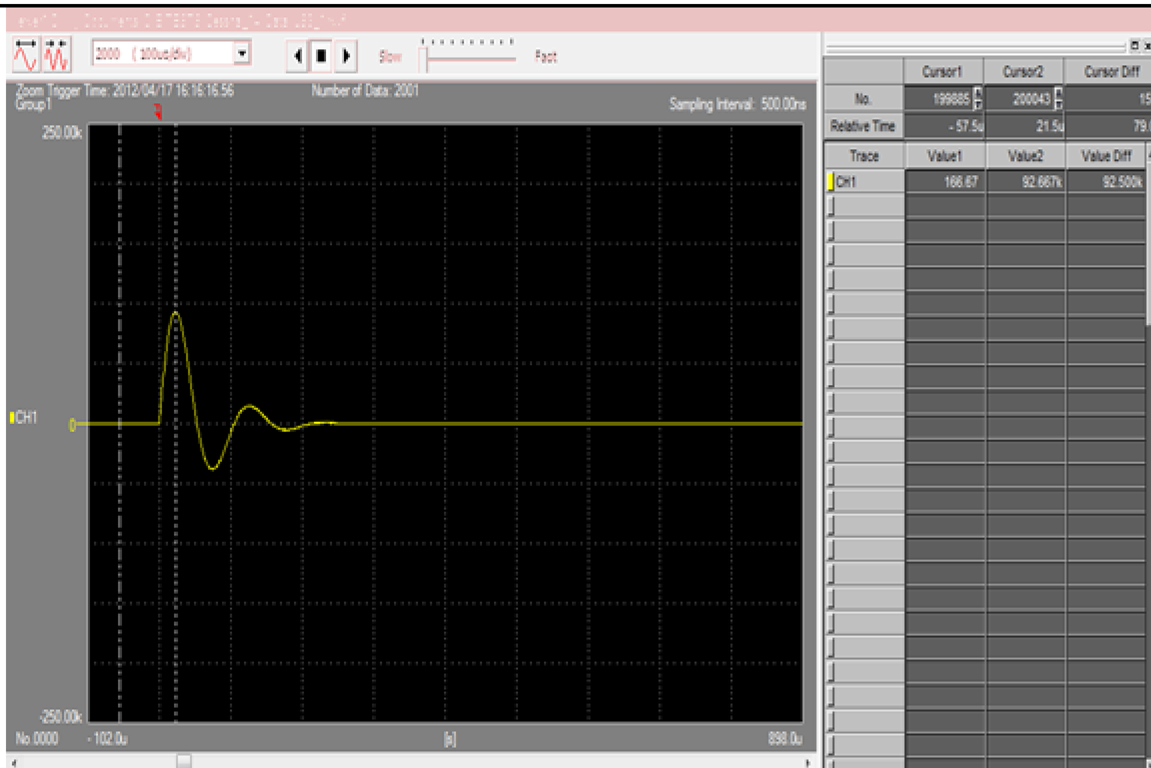


HIGH CURRENT – COMPONENT C* | Ip = 84 Amps | 50 mS / Div

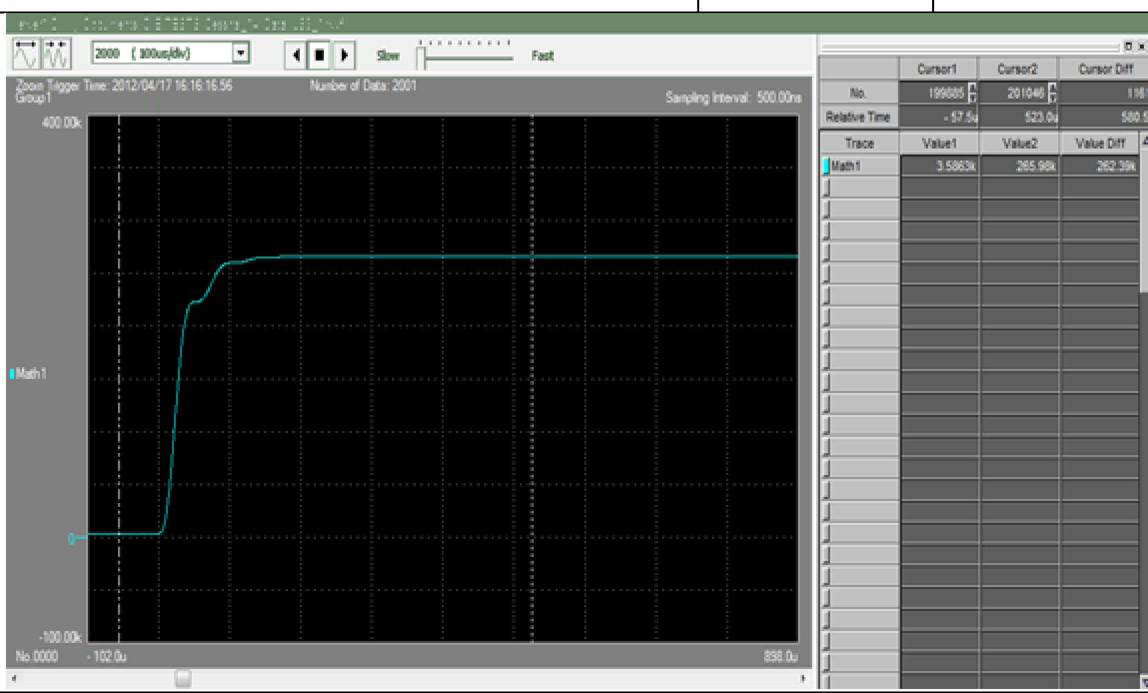


COMPONENT C* CHARGE TRANSFER | 0.2 Coulombs

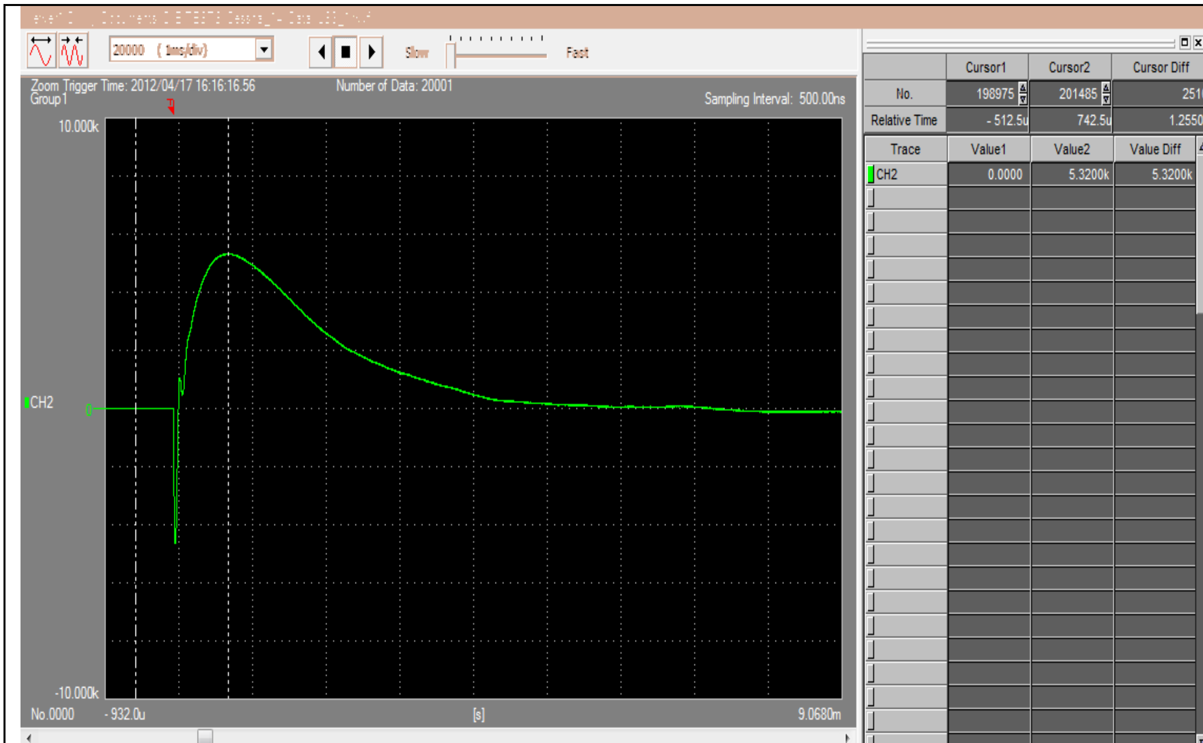
PANEL: LS-5



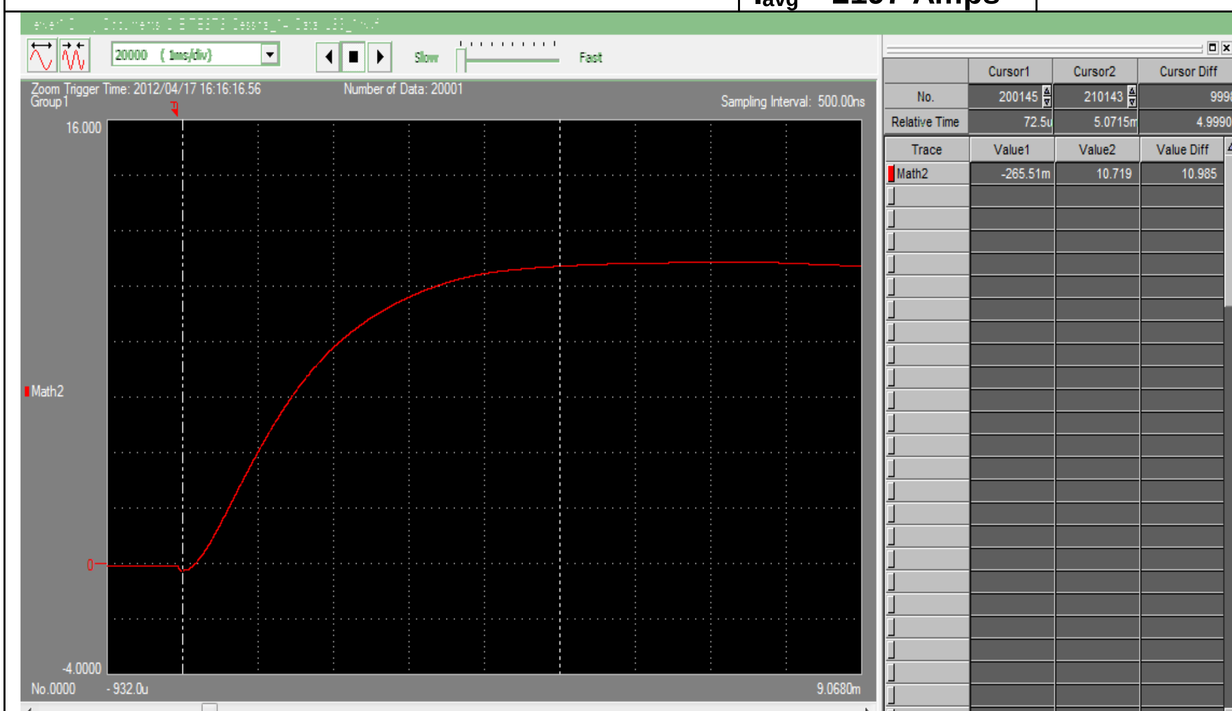
HIGH CURRENT – COMPONENT D	**Ip = 92.5 KA**	**100 uS / Div**



COMPONENT D ACTION INTEGRAL	**AI = 262390 A^2-S**
PANEL: LS-6	

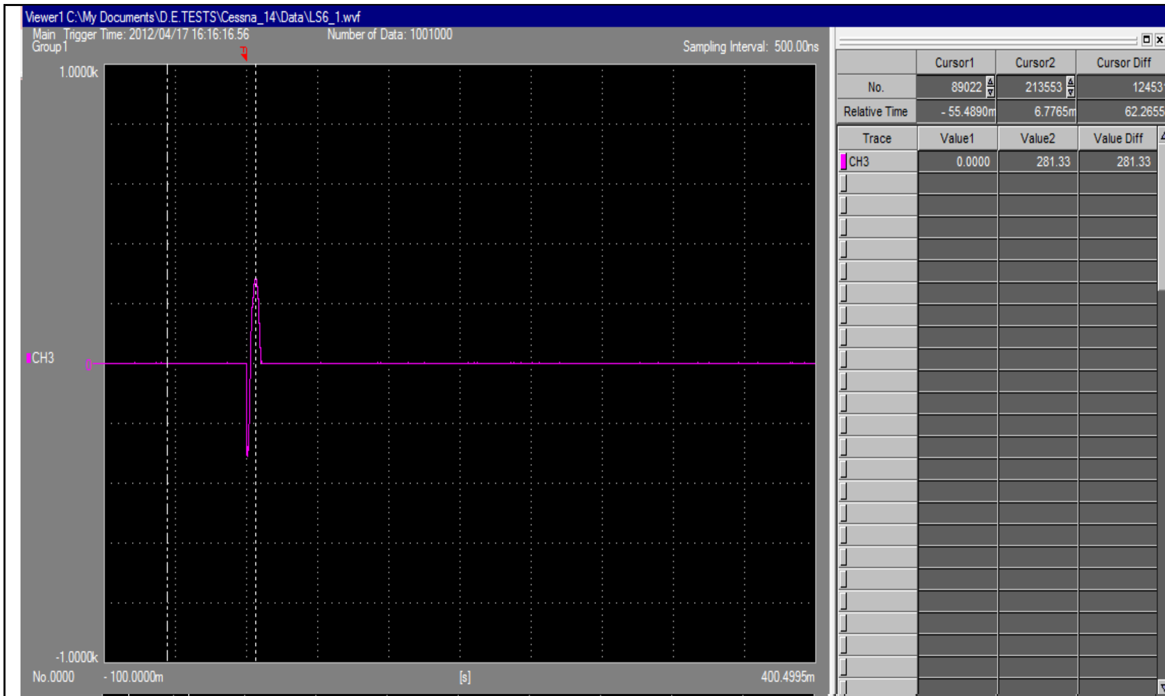


HIGH CURRENT – COMPONENT B	I_P = 5320 Amps I_{avg} = 2197 Amps	1 mS / Div

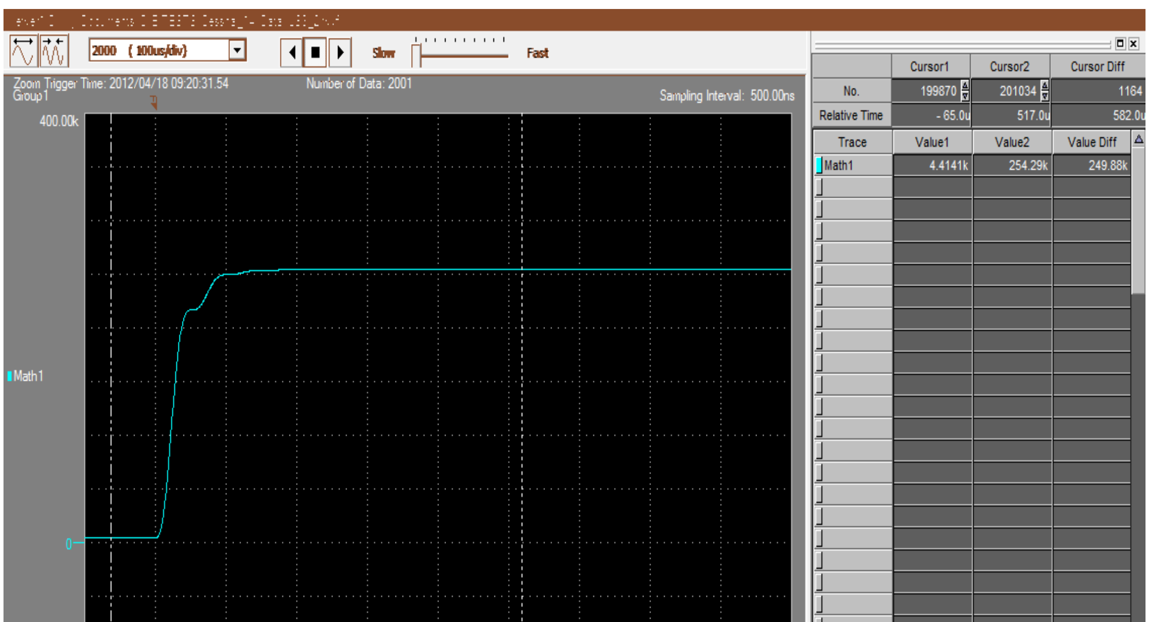


COMPONENT B CHARGE TRANSFER	10.985 Coulombs

PANEL: LS-6

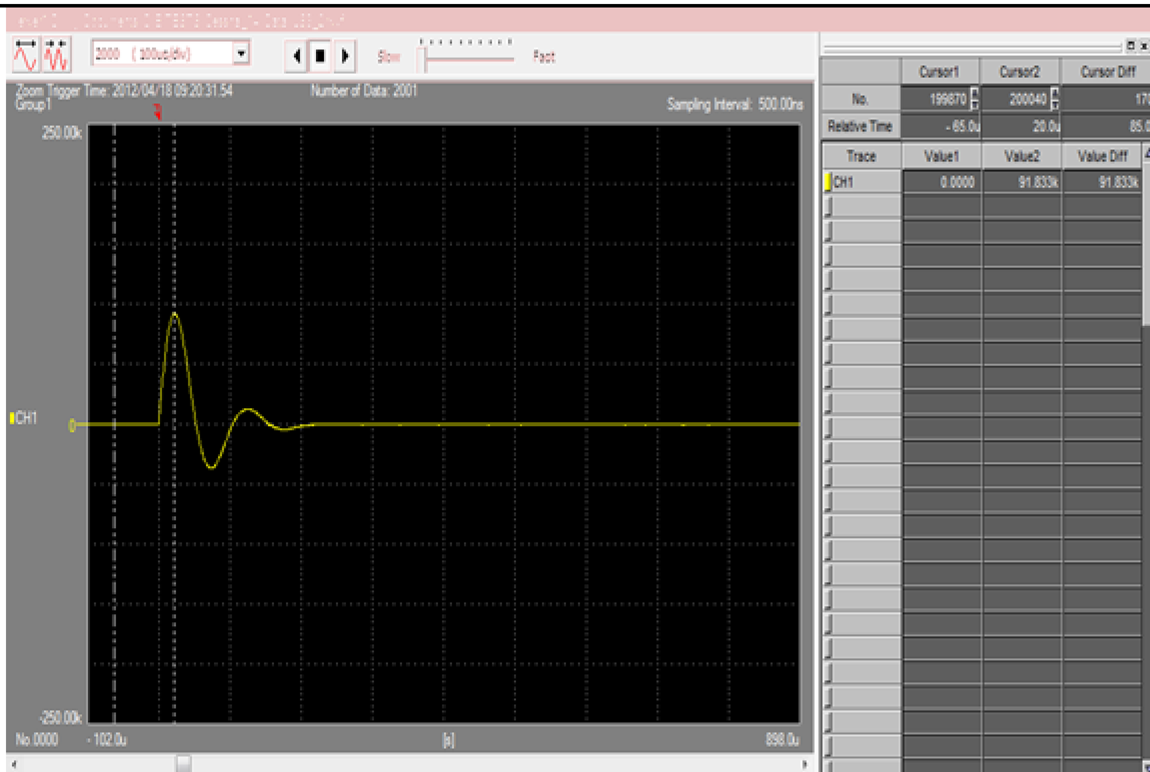


HIGH CURRENT – COMPONENT C*	Ip = 281 Amps	50 mS / Div

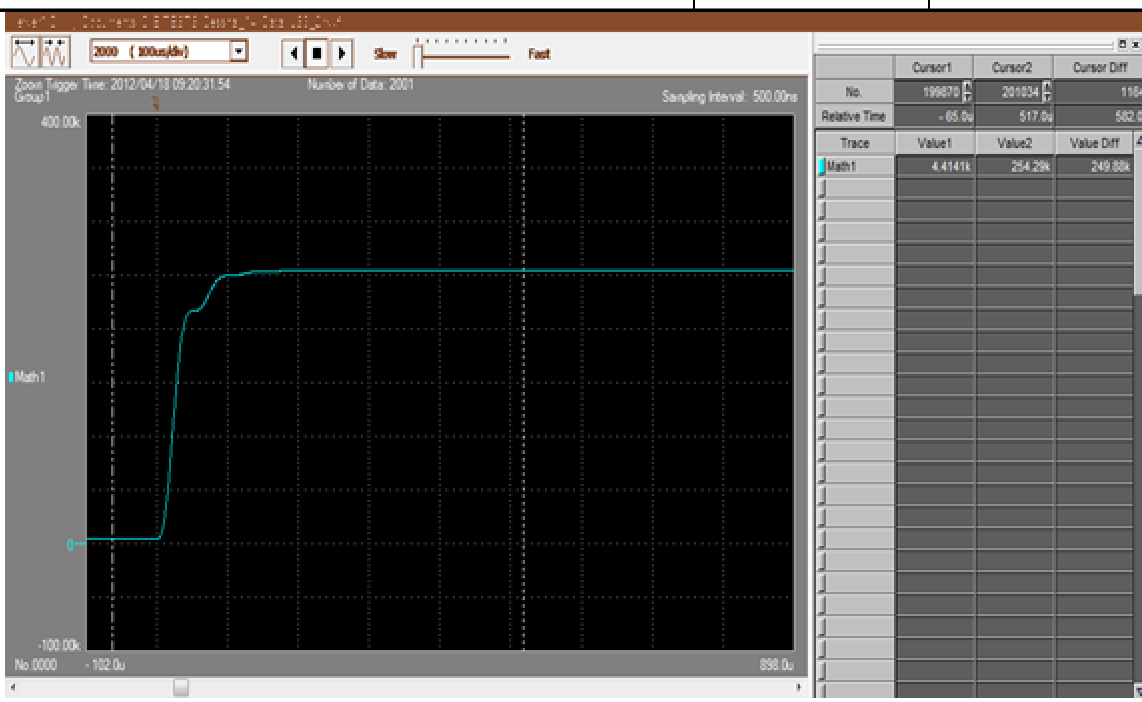


COMPONENT C* CHARGE TRANSFER	0.82 Coulombs

PANEL: LS-6

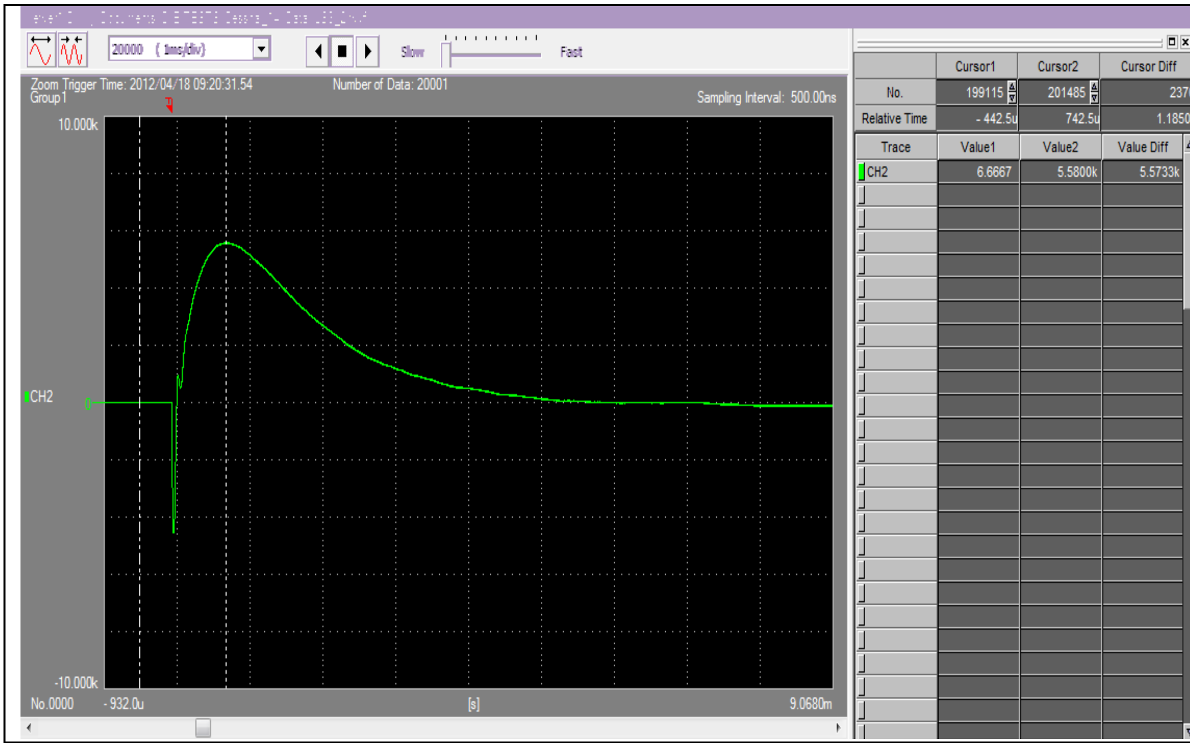


HIGH CURRENT – COMPONENT D	Ip = 91.8 KA	100 uS / Div

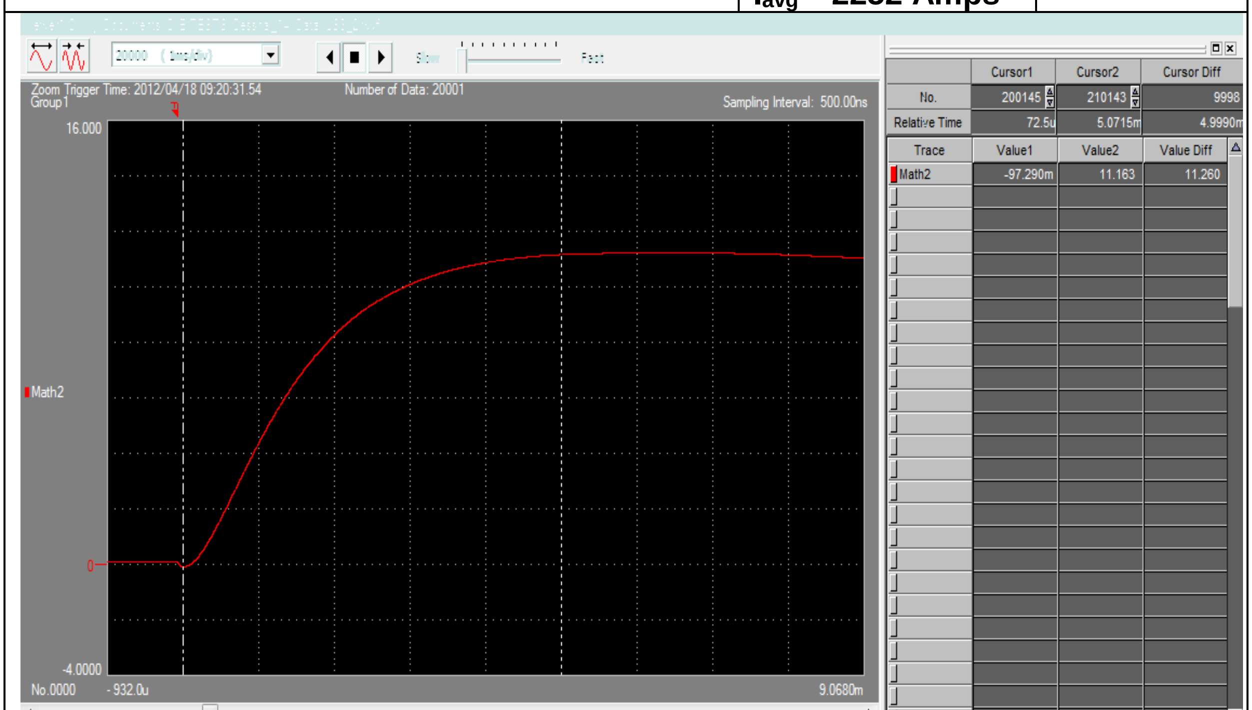


COMPONENT D ACTION INTEGRAL	AI = 249880 A^2-S

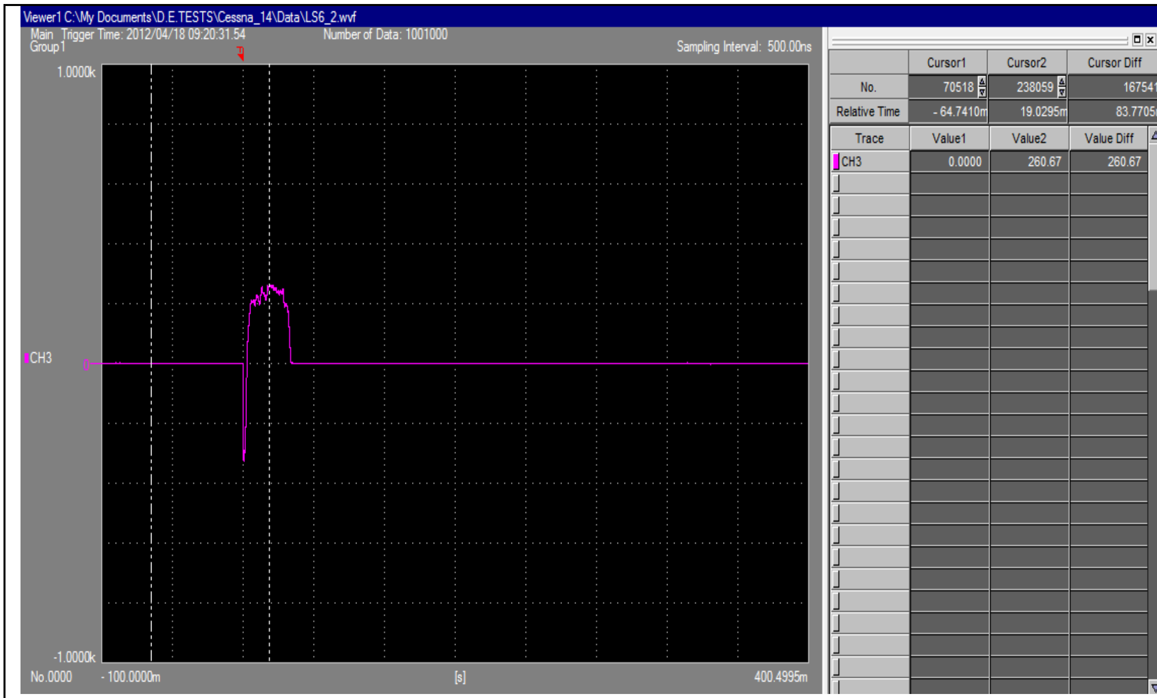
PANEL: LS-6 Second Strike



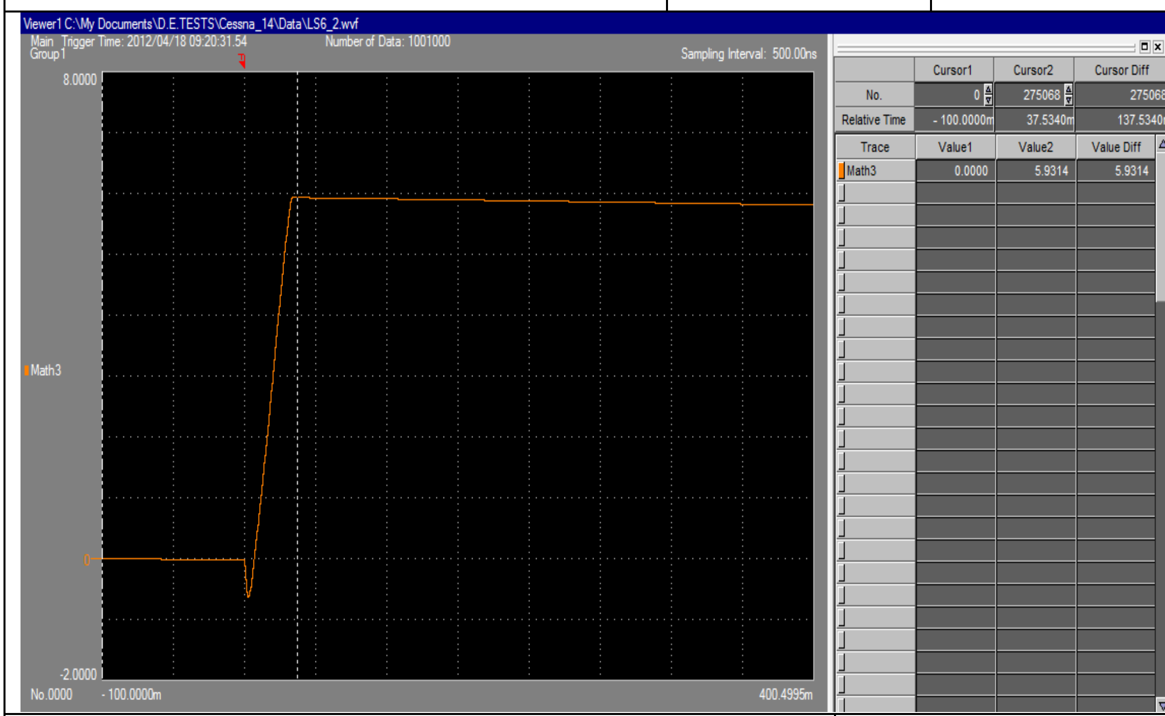
HIGH CURRENT – COMPONENT B	I_P = 5573 Amps I_{avg} = 2252 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.260 Coulombs
PANEL: LS-6 Second Strike	

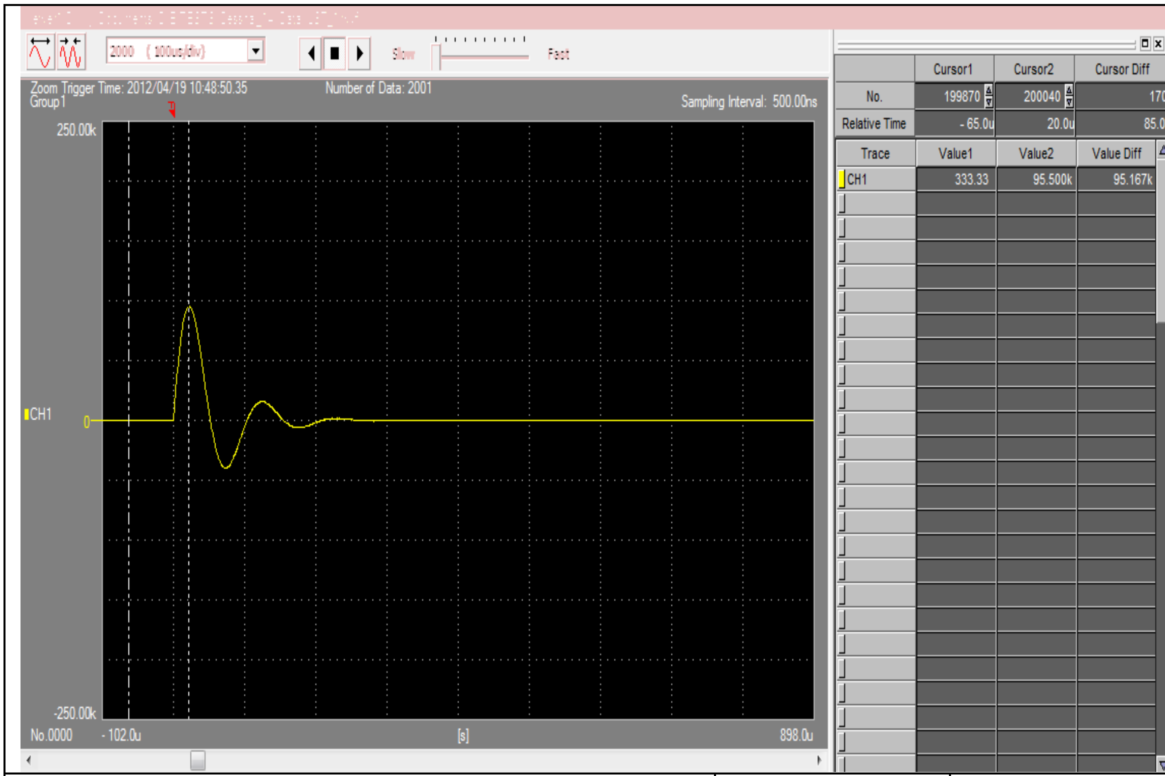


HIGH CURRENT – COMPONENT C*	Ip = 261 Amps	50 mS / Div

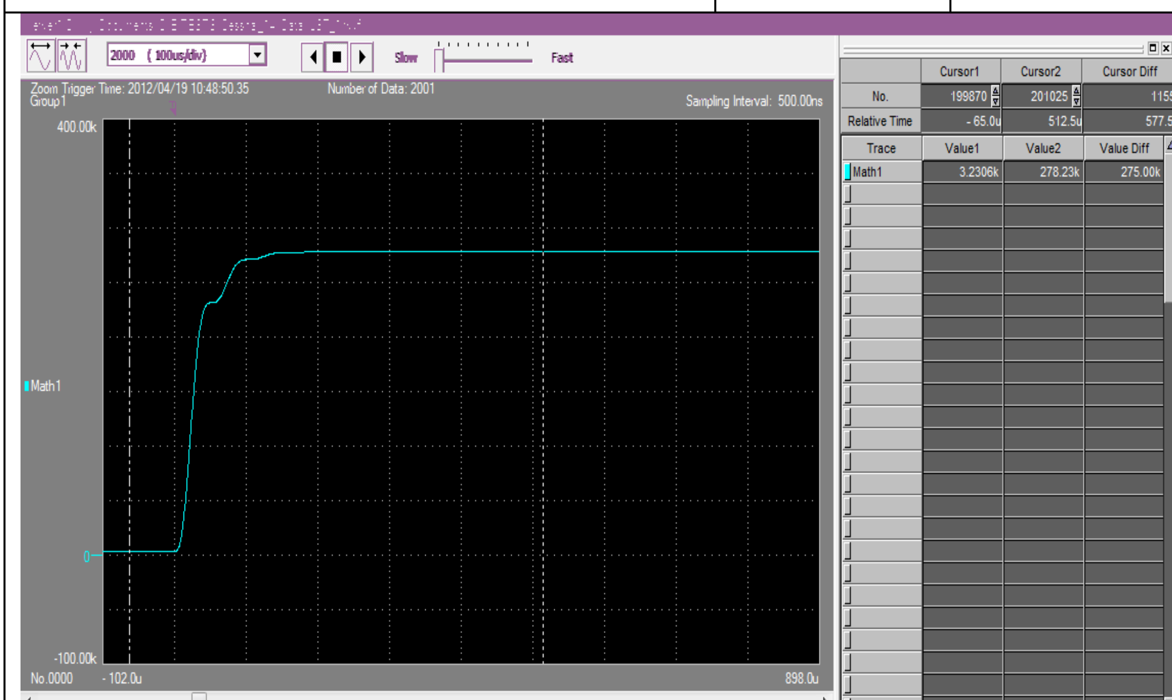


COMPONENT C* CHARGE TRANSFER	5.9 Coulombs

PANEL: LS-6 Second Strike

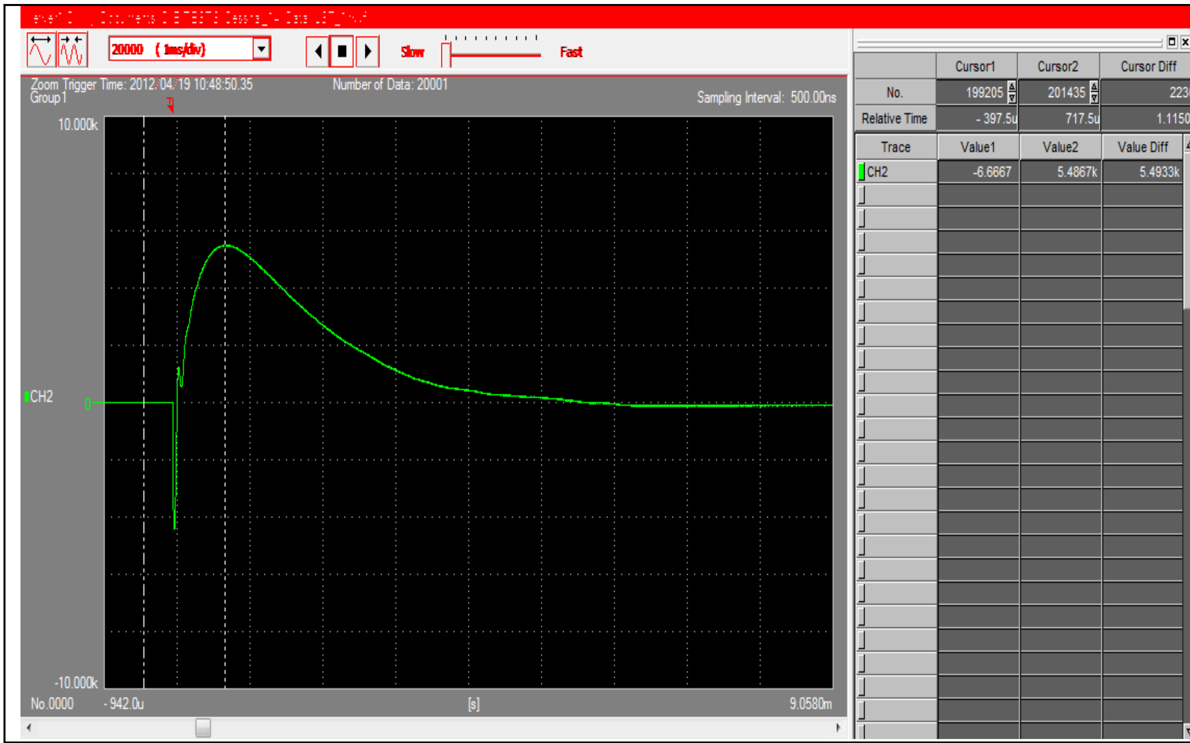


HIGH CURRENT – COMPONENT D	**Ip = 95.2 KA**	**100 uS / Div**

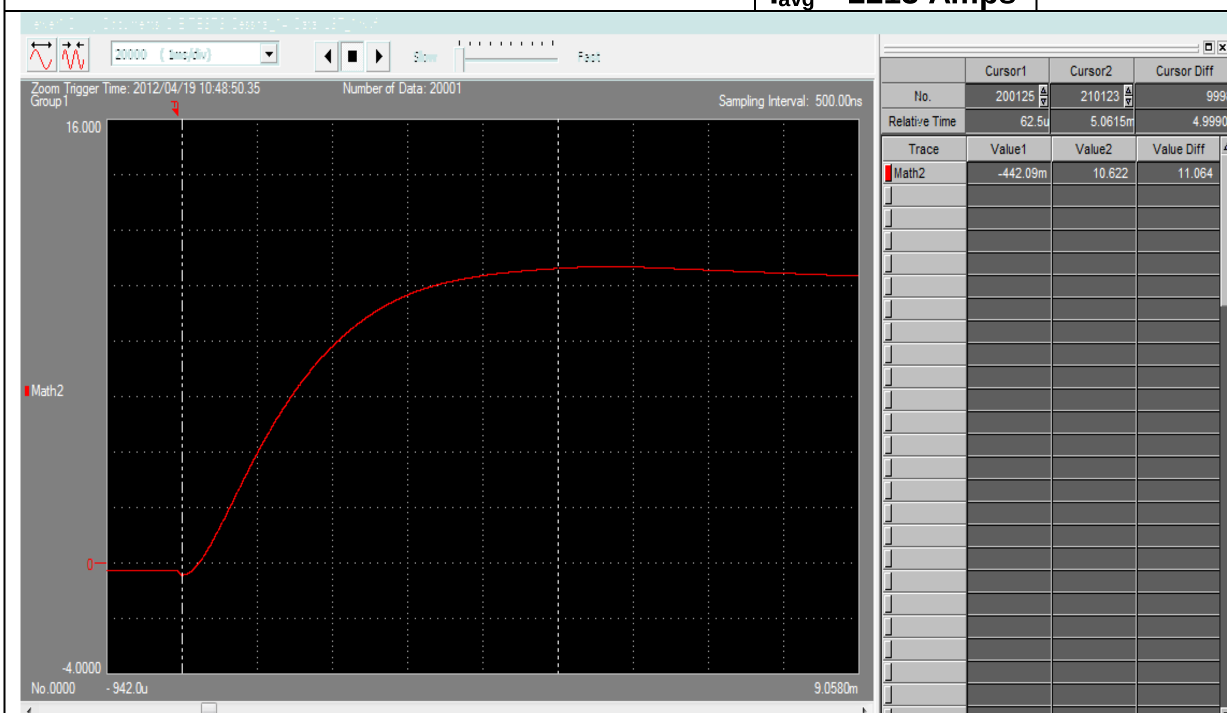


COMPONENT D ACTION INTEGRAL	**AI = 275000 A^2-S**

PANEL: LS-7

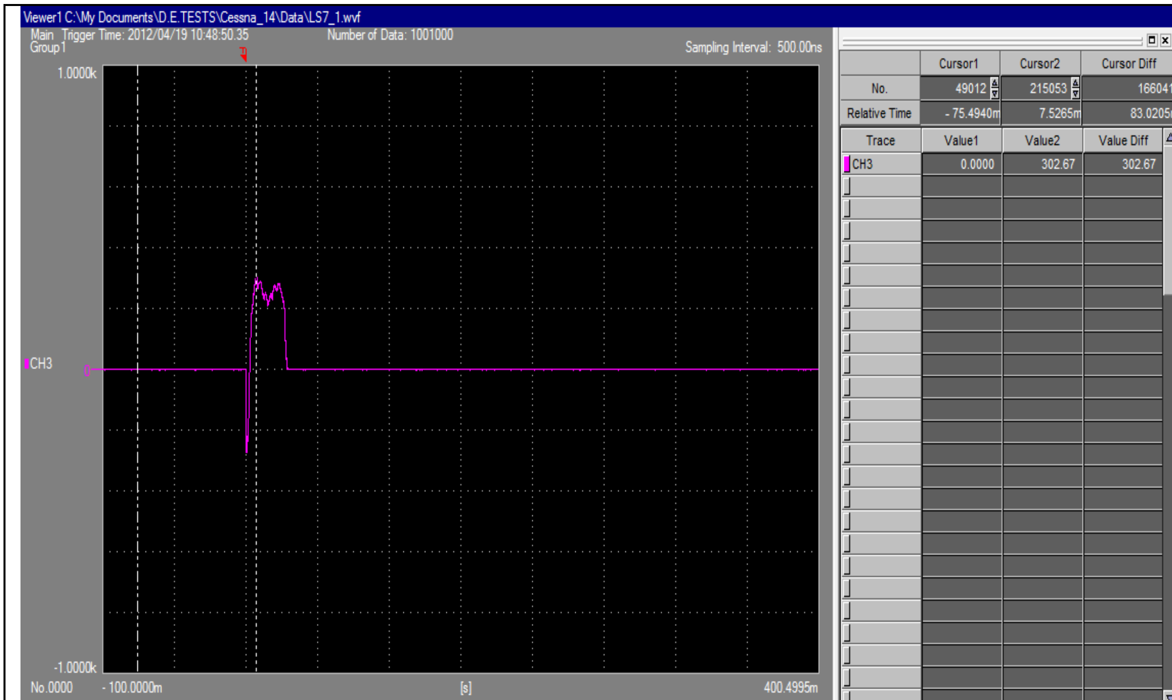


HIGH CURRENT – COMPONENT B	**I_P = 5493 Amps** **I_{avg} = 2213 Amps**	**1 mS / Div**

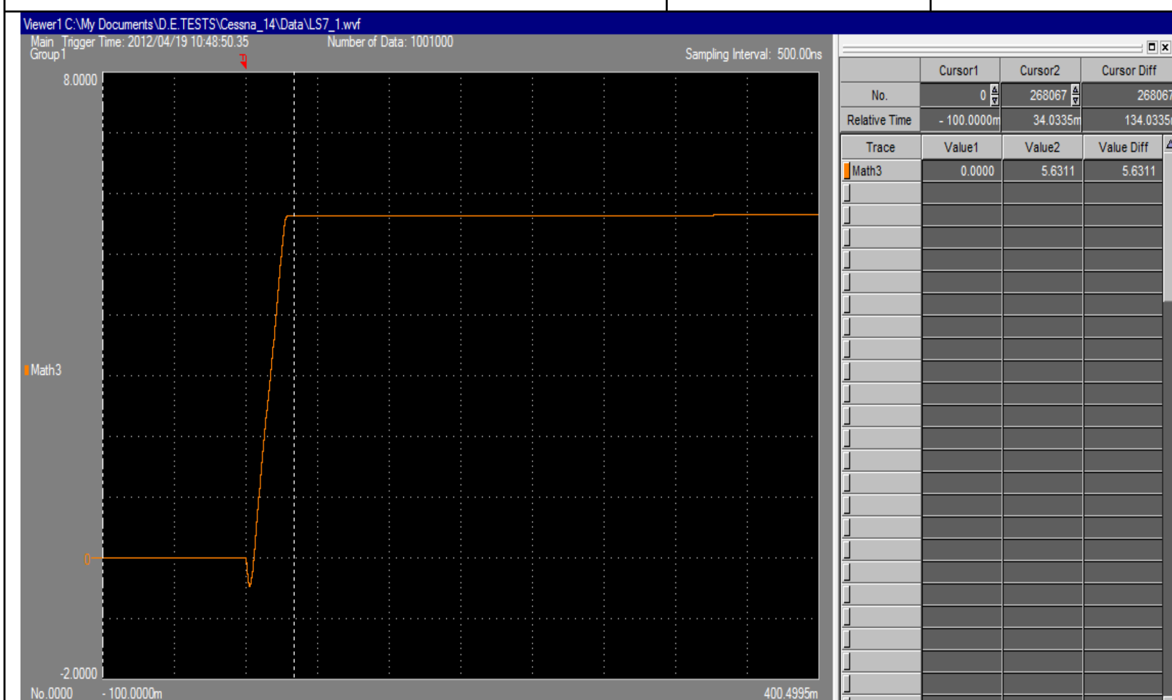


COMPONENT B CHARGE TRANSFER	**11.064 Coulombs**

PANEL: LS-7

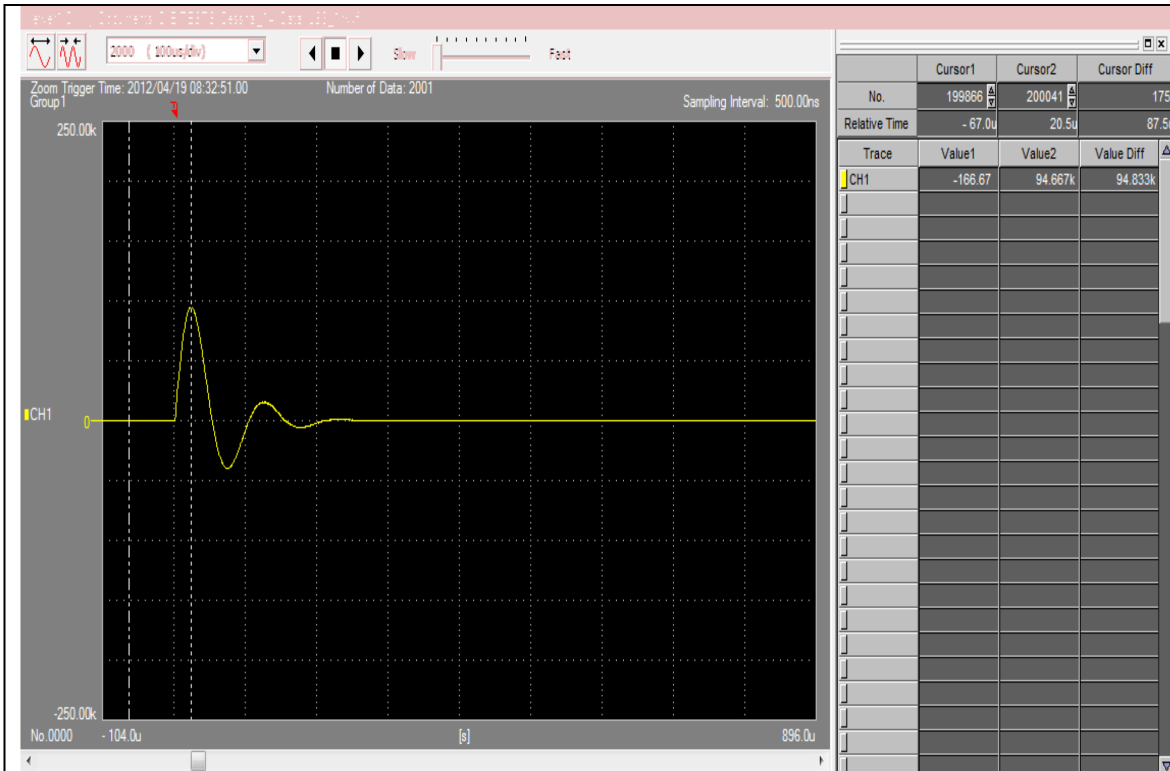


HIGH CURRENT – COMPONENT C*	Ip = 303 Amps	50 mS / Div

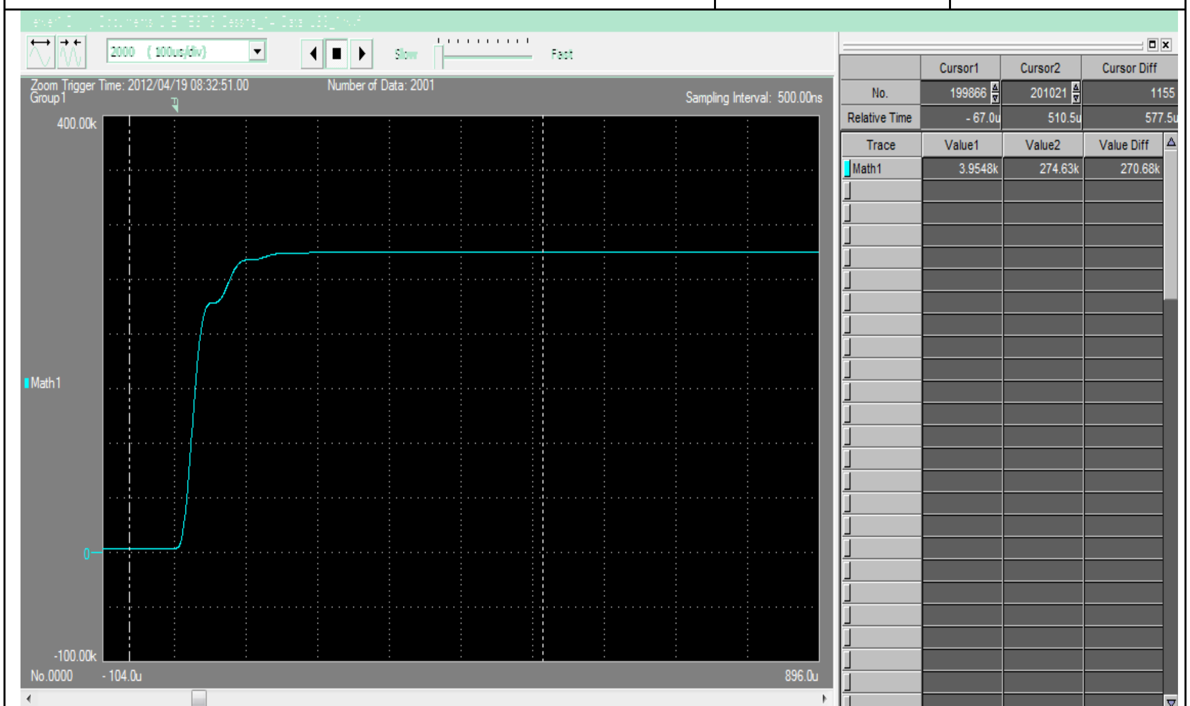


COMPONENT C* CHARGE TRANSFER	5.6 Coulombs

PANEL: LS-7

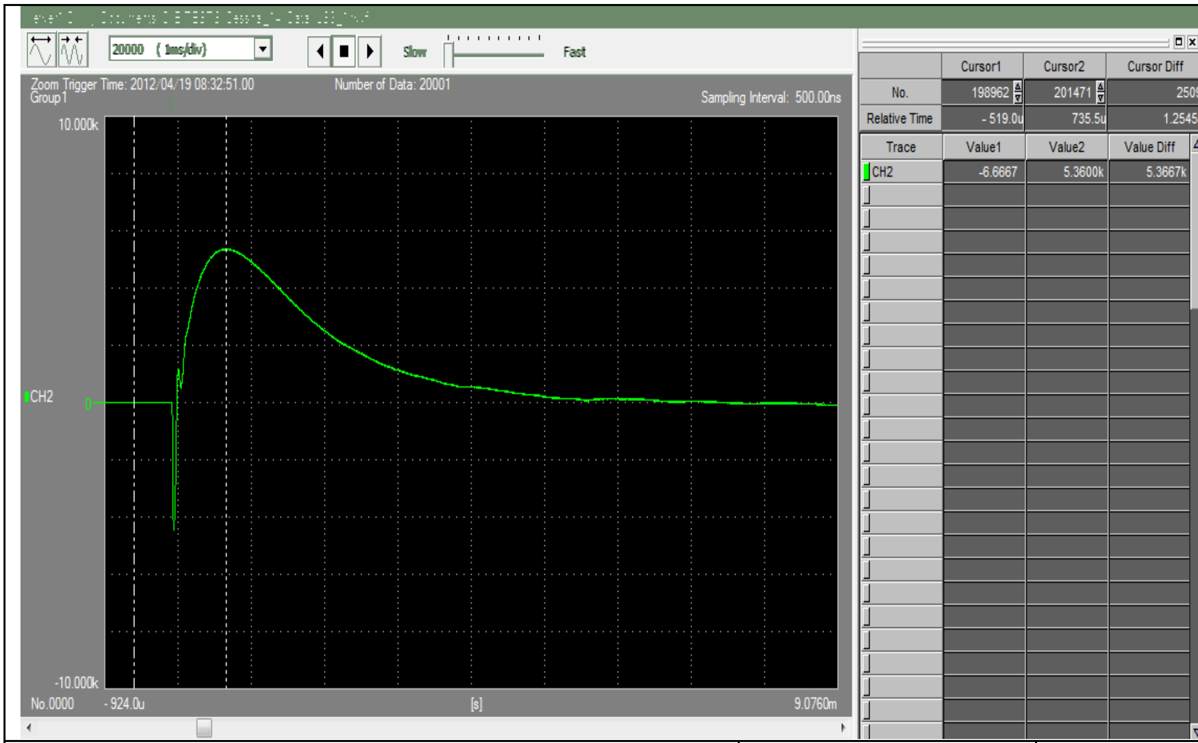


HIGH CURRENT – COMPONENT D	Ip = 94.8 KA	100 uS / Div

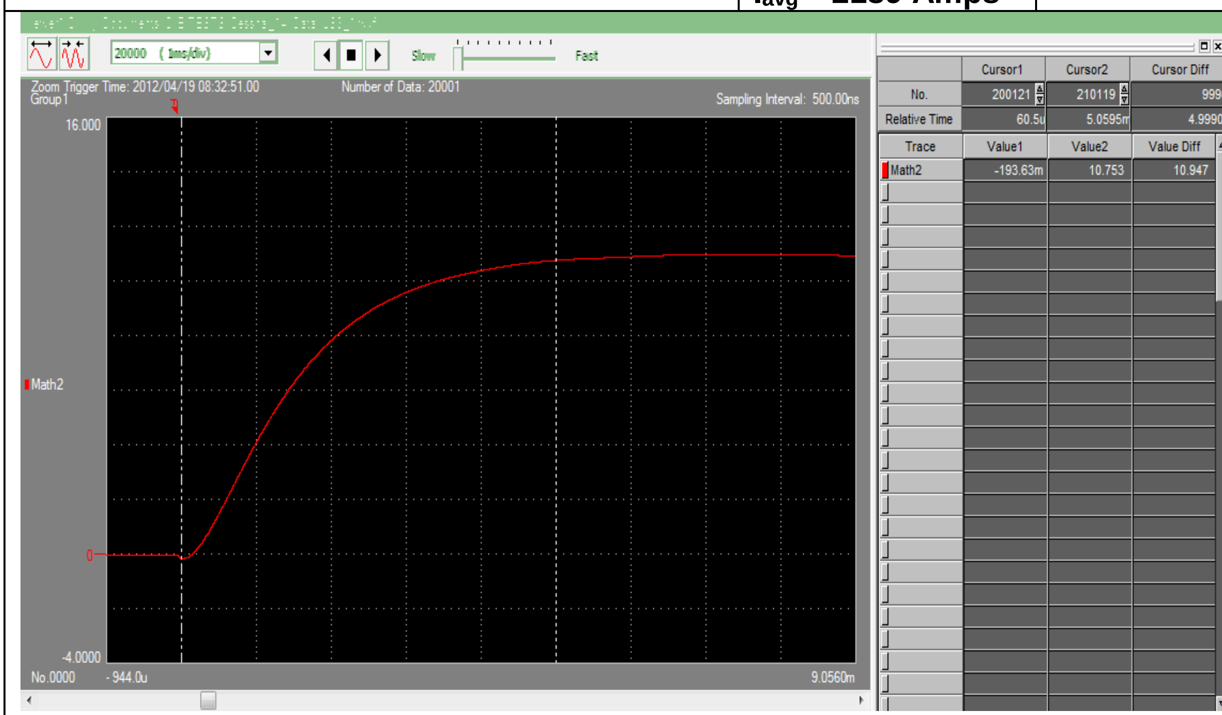


COMPONENT D ACTION INTEGRAL	AI = 270680 A^2-S

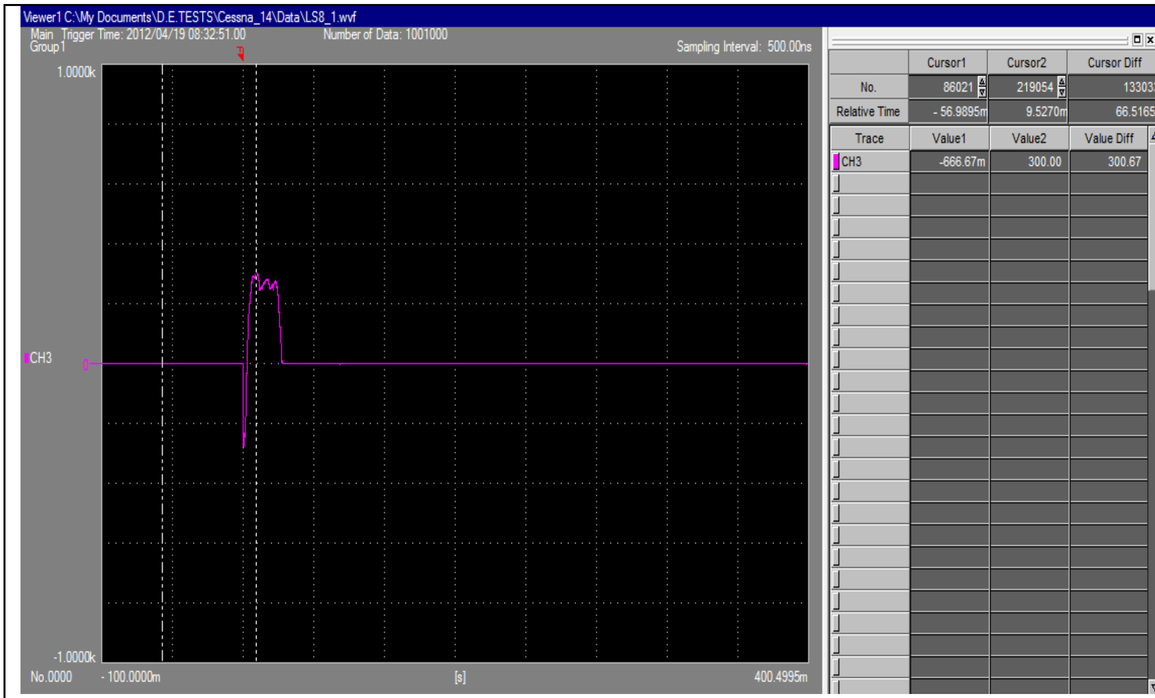
PANEL: LS-8



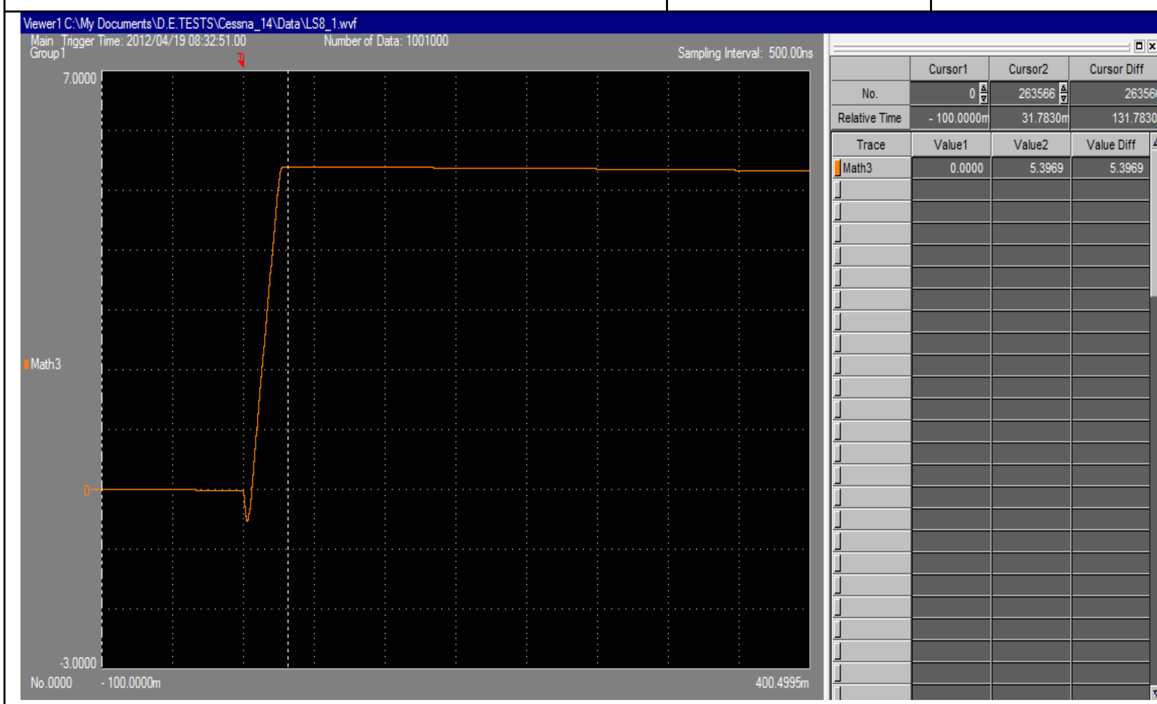
HIGH CURRENT – COMPONENT B	I_P = 5367 Amps I_{avg} = 2189 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.947 Coulombs
PANEL: LS-8	

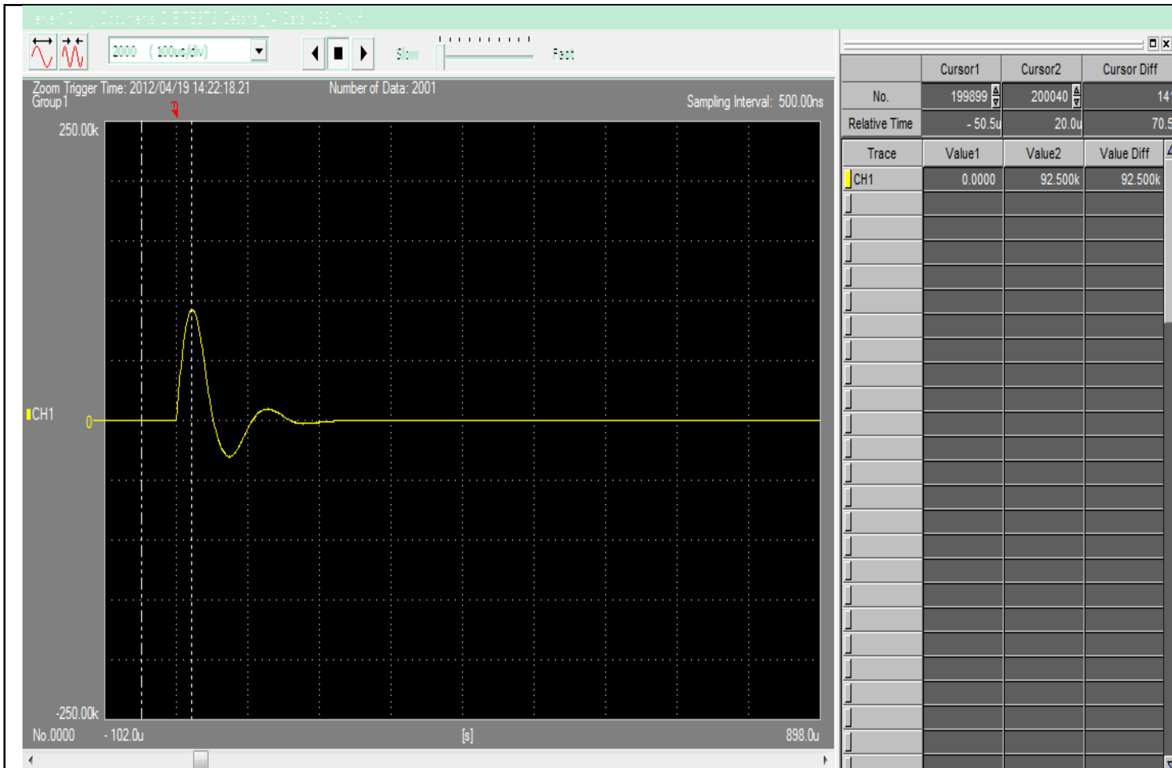


HIGH CURRENT – COMPONENT C*	Ip = 301 Amps	50 mS / Div

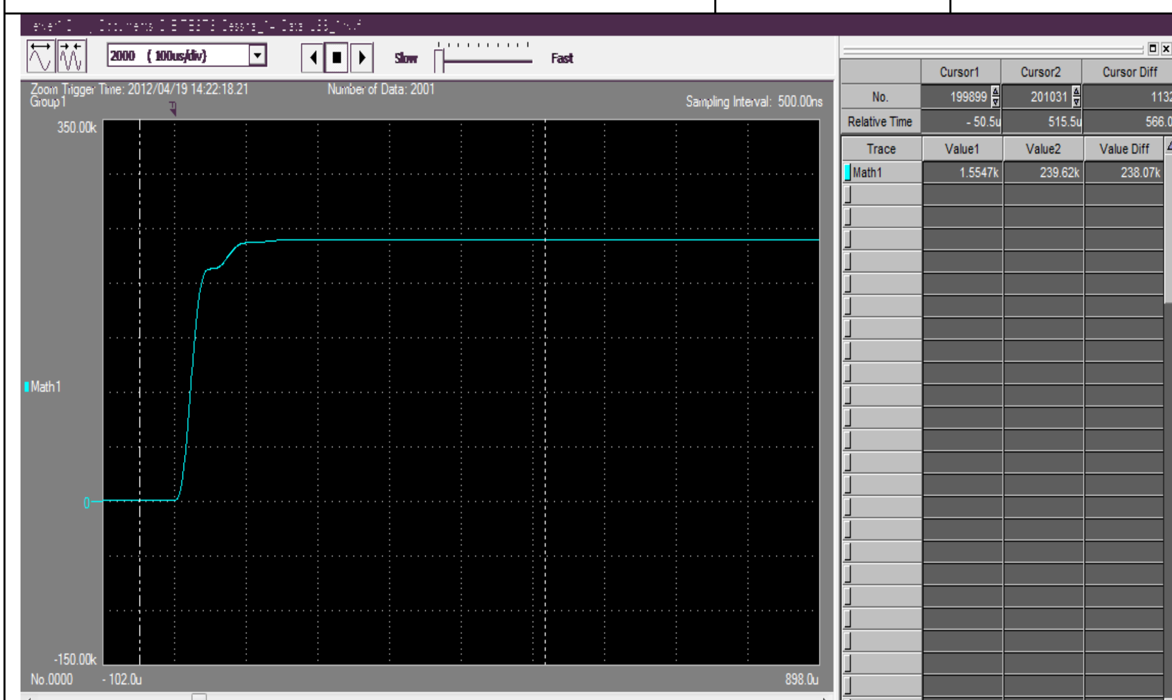


COMPONENT C* CHARGE TRANSFER	5.4 Coulombs

PANEL: LS-8

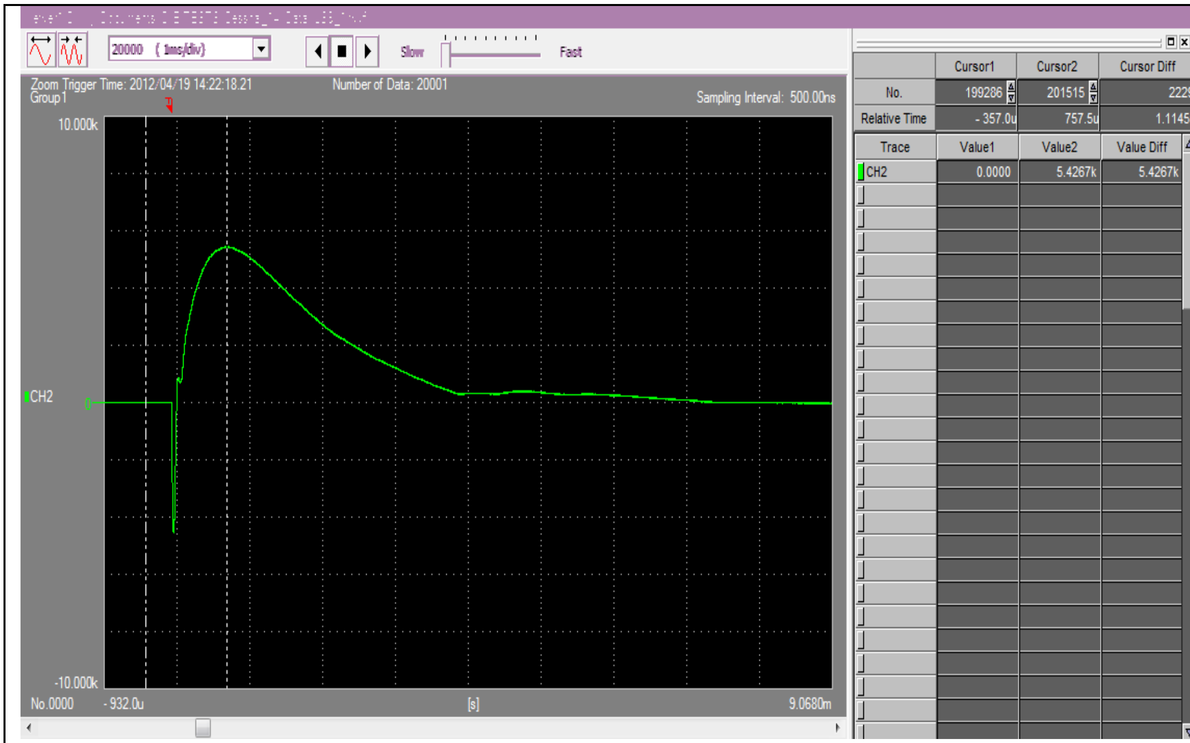


HIGH CURRENT – COMPONENT D	Ip = 92.5 KA	100 uS / Div

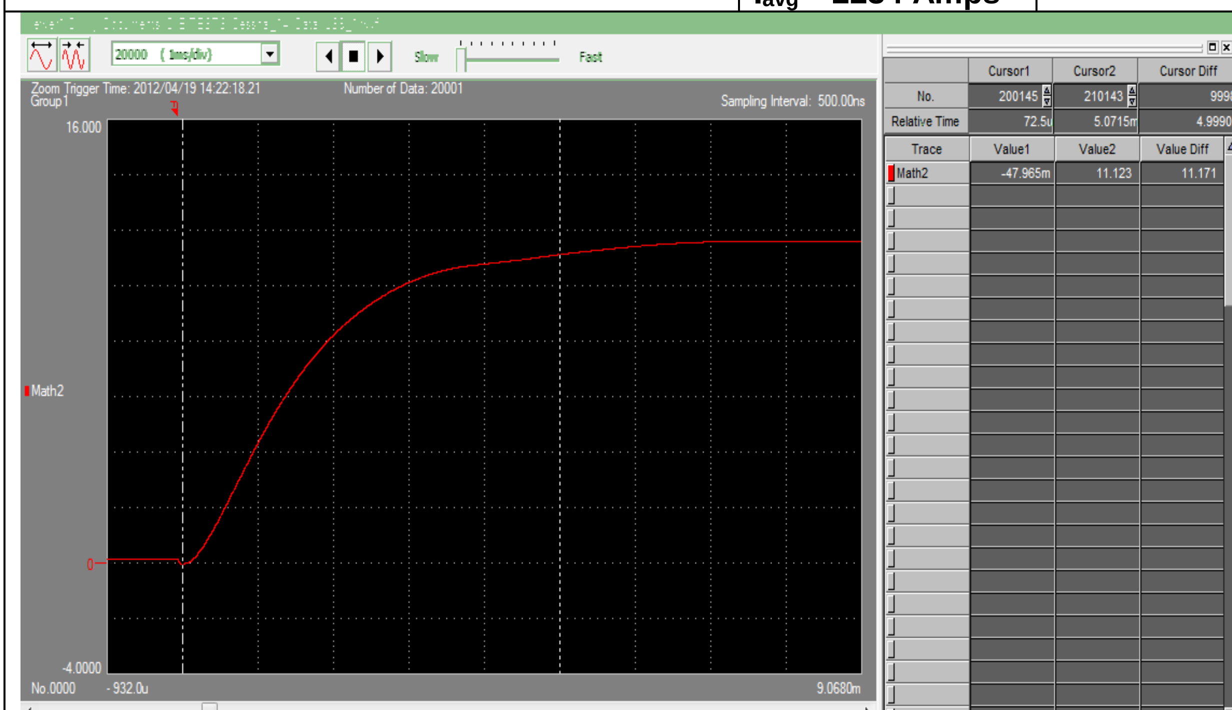


COMPONENT D ACTION INTEGRAL	AI = 238070 A^2-S

PANEL: LS-9

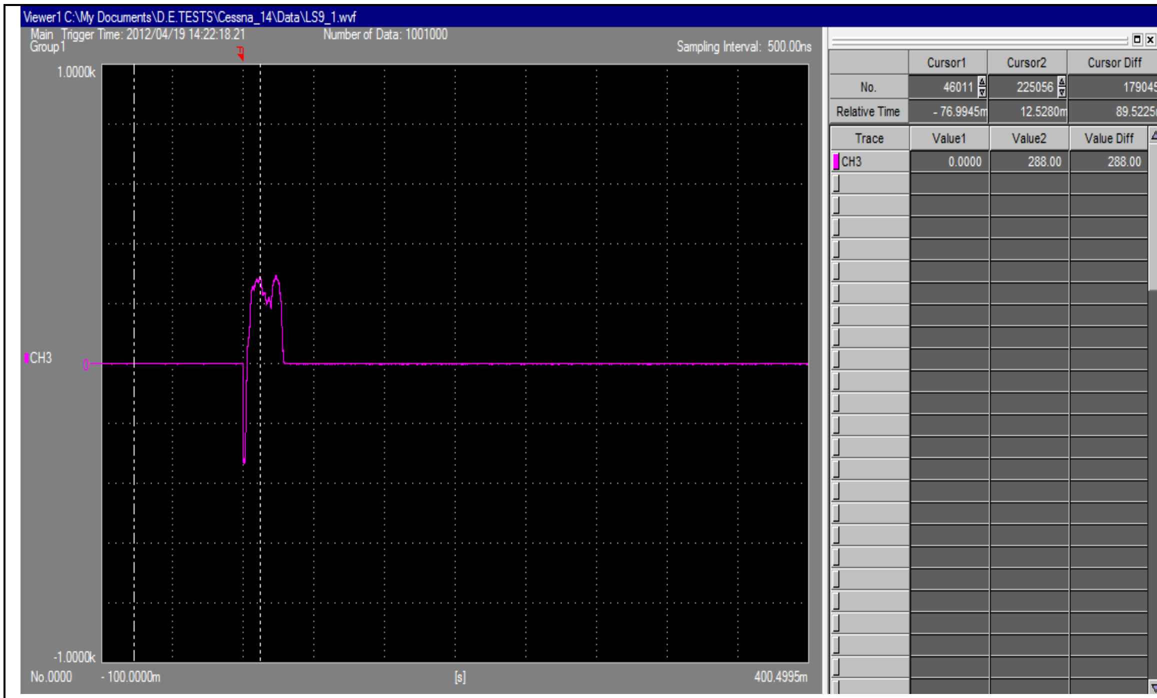


HIGH CURRENT – COMPONENT B	I_P = 5427 Amps I_{avg} = 2234 Amps	1 mS / Div

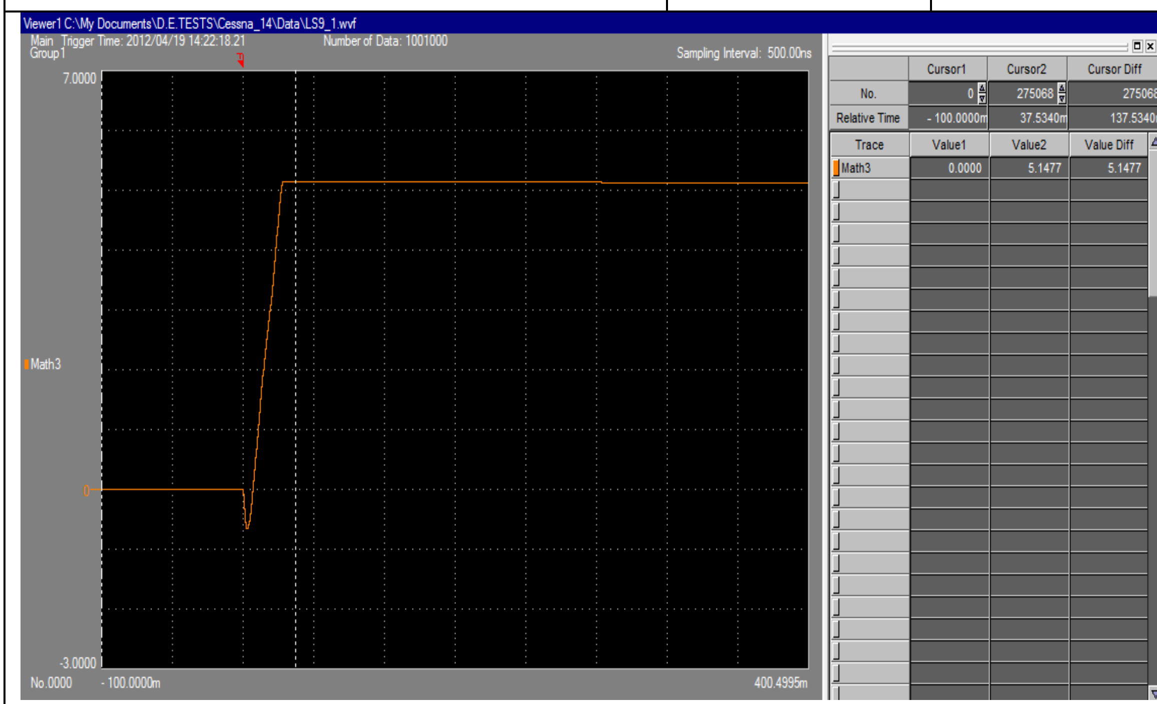


COMPONENT B CHARGE TRANSFER	11.171 Coulombs

PANEL: LS-9

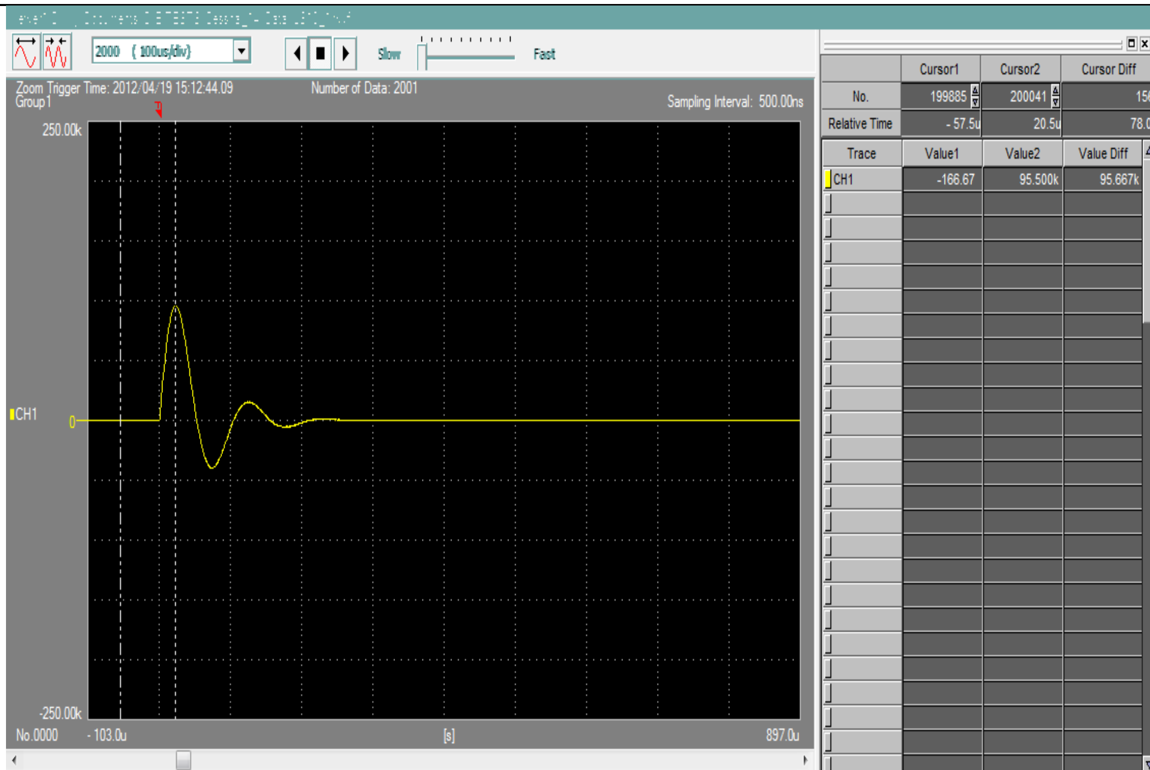


HIGH CURRENT – COMPONENT C*	Ip = 288 Amps	50 mS / Div

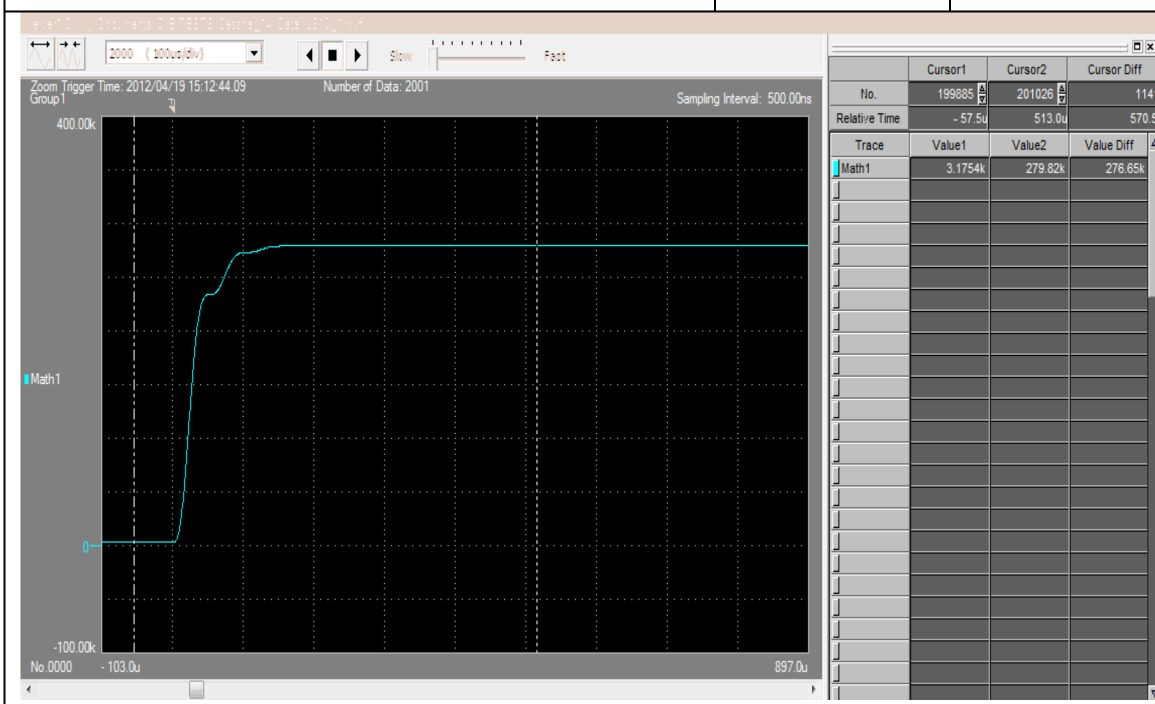


COMPONENT C* CHARGE TRANSFER	5.1 Coulombs

PANEL: LS-9

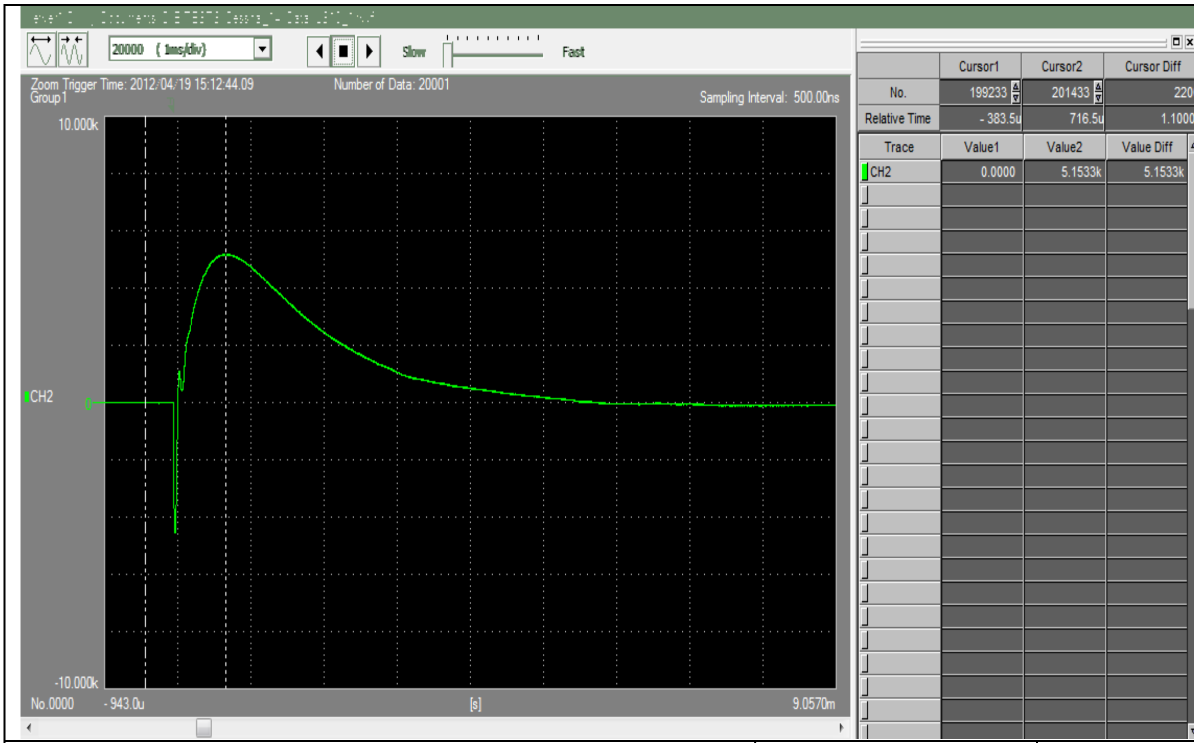


HIGH CURRENT – COMPONENT D	**Ip = 95.7 KA**	**100 uS / Div**

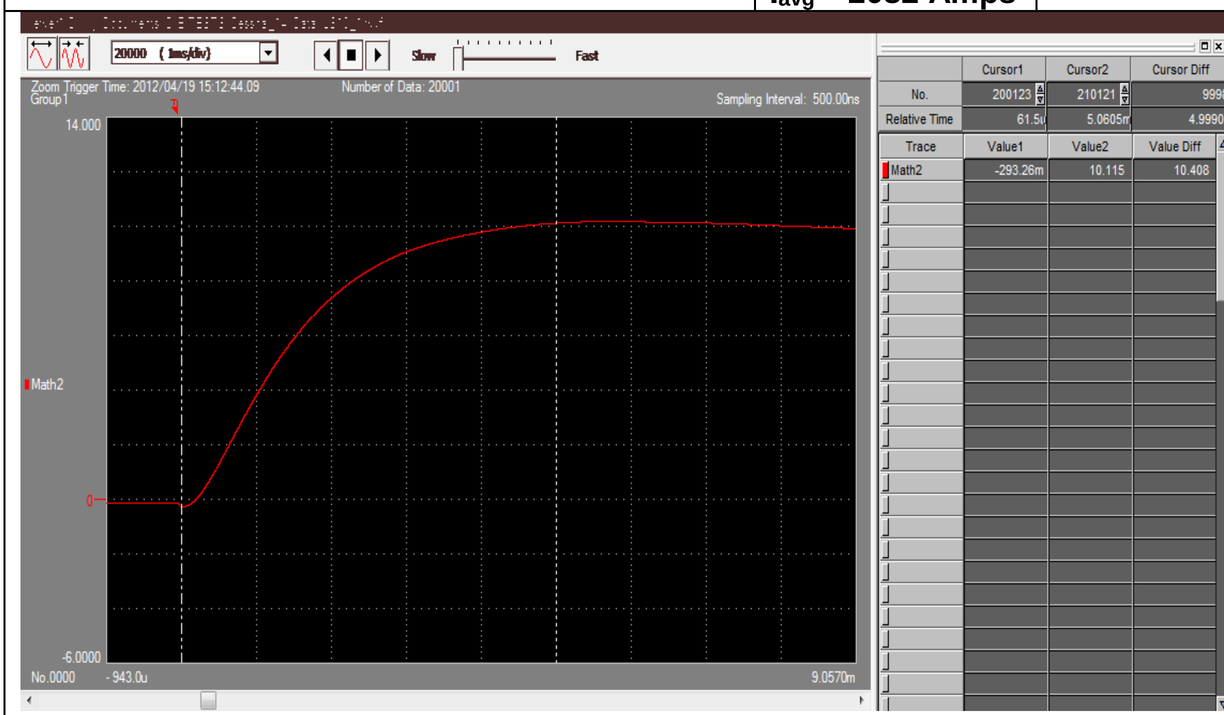


COMPONENT D ACTION INTEGRAL	**AI = 276650 A^2-S**

PANEL: LS-10

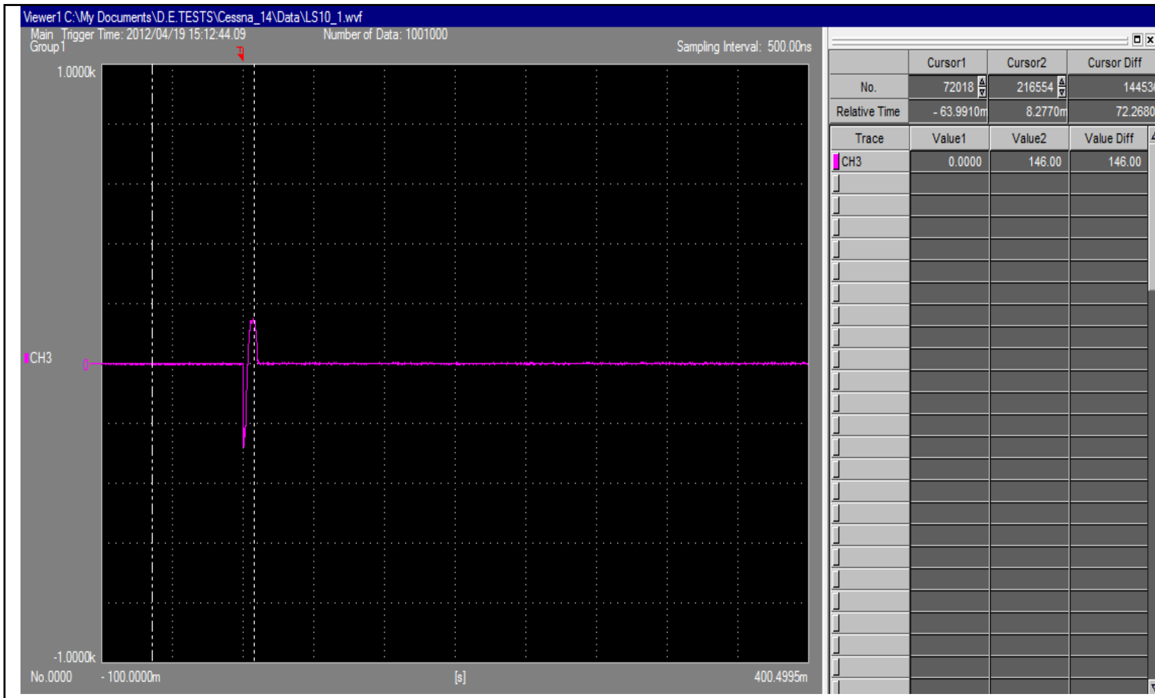


HIGH CURRENT – COMPONENT B	I_P = 5153 Amps I_{avg} = 2082 Amps	1 mS / Div

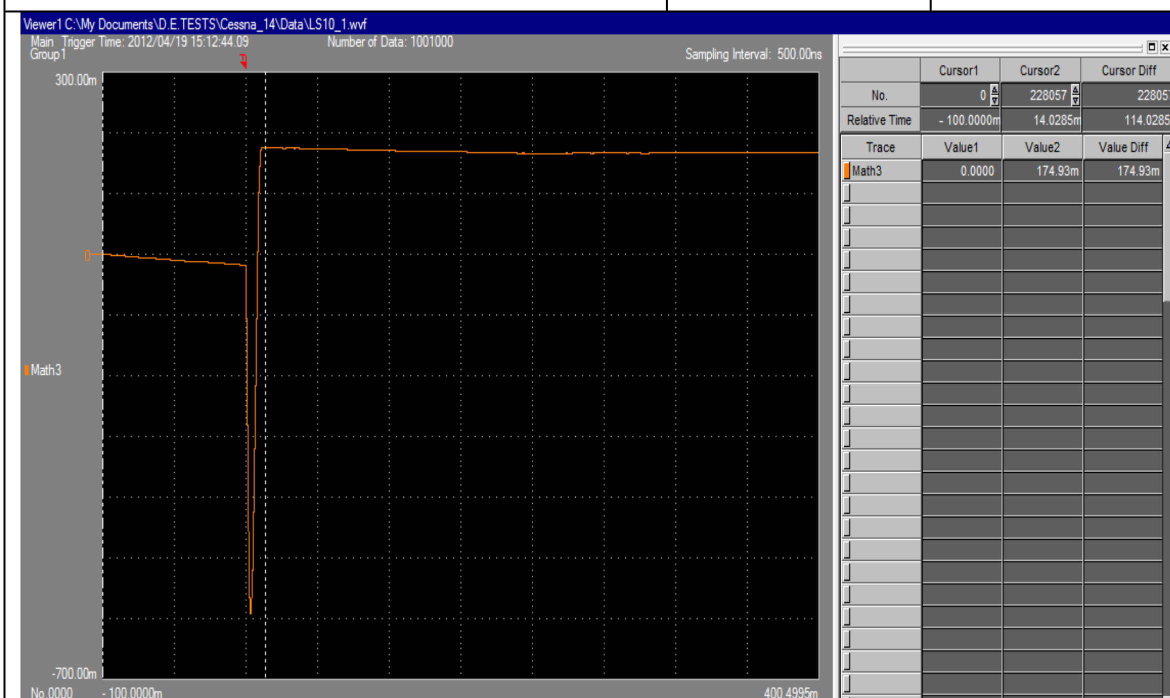


COMPONENT B CHARGE TRANSFER	10.408 Coulombs

PANEL: LS-10

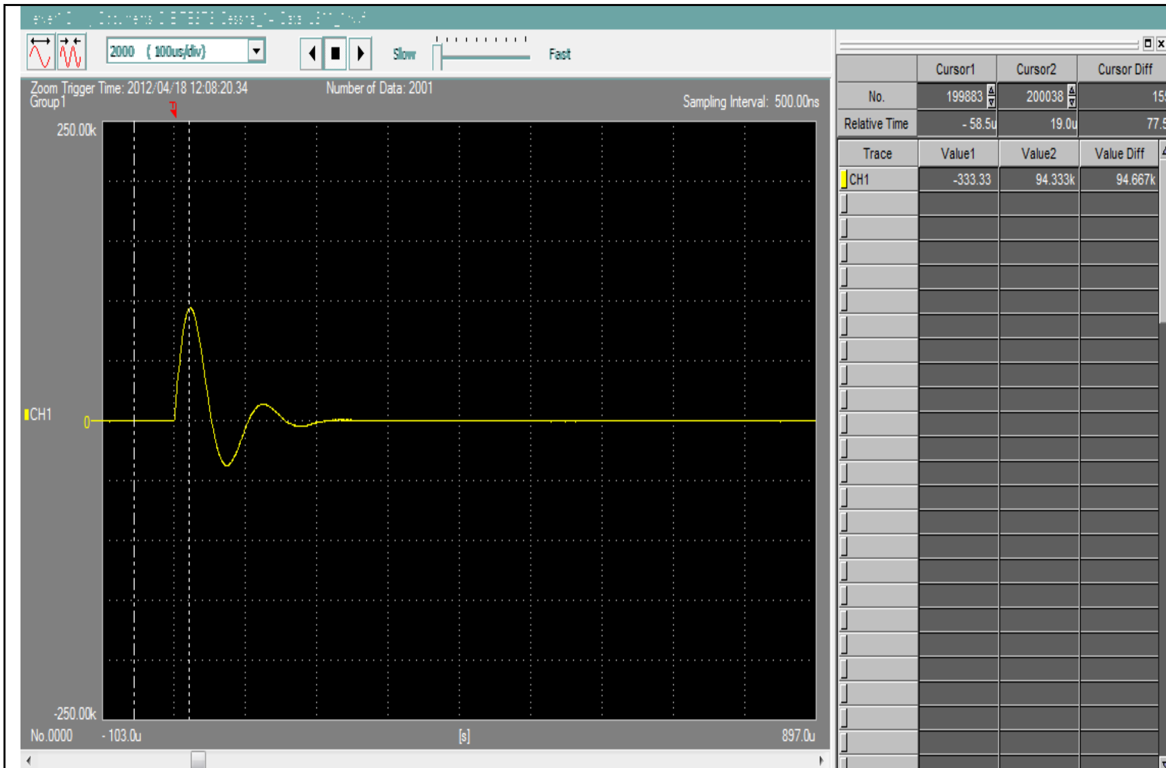


HIGH CURRENT – COMPONENT C*	Ip = 146 Amps	50 mS / Div

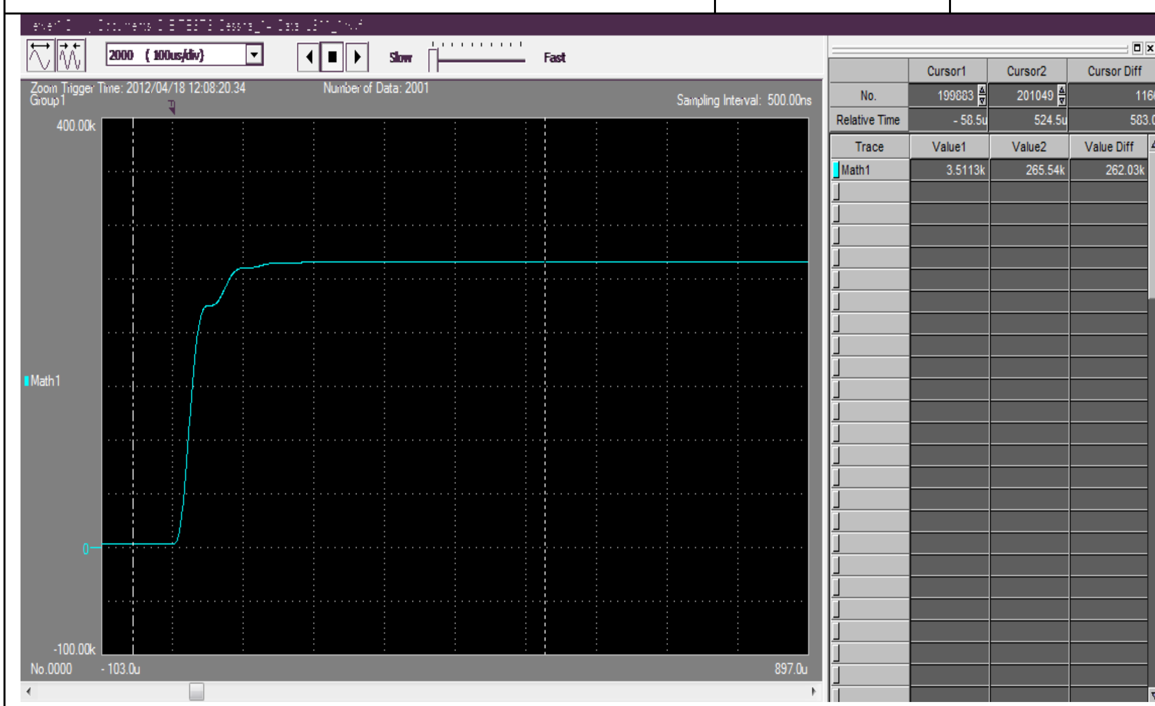


COMPONENT C* CHARGE TRANSFER	0.17 Coulombs

PANEL: LS-10

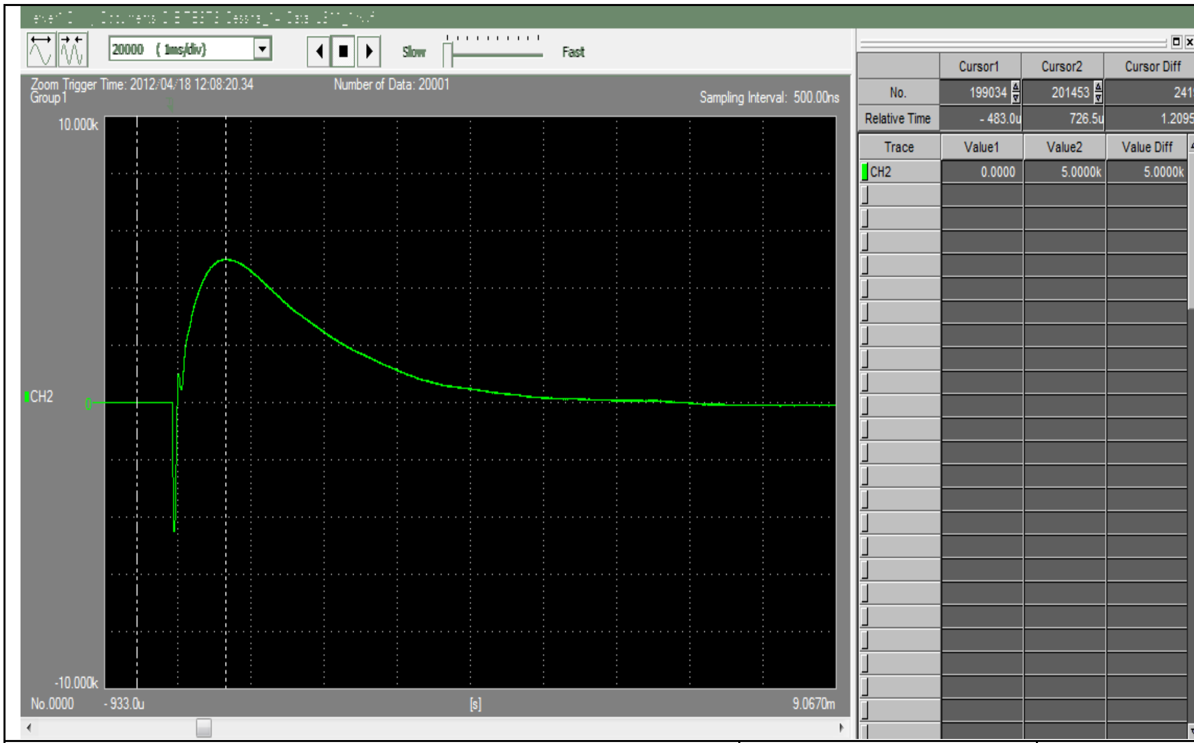


HIGH CURRENT – COMPONENT D	Ip = 94.7 KA	100 uS / Div

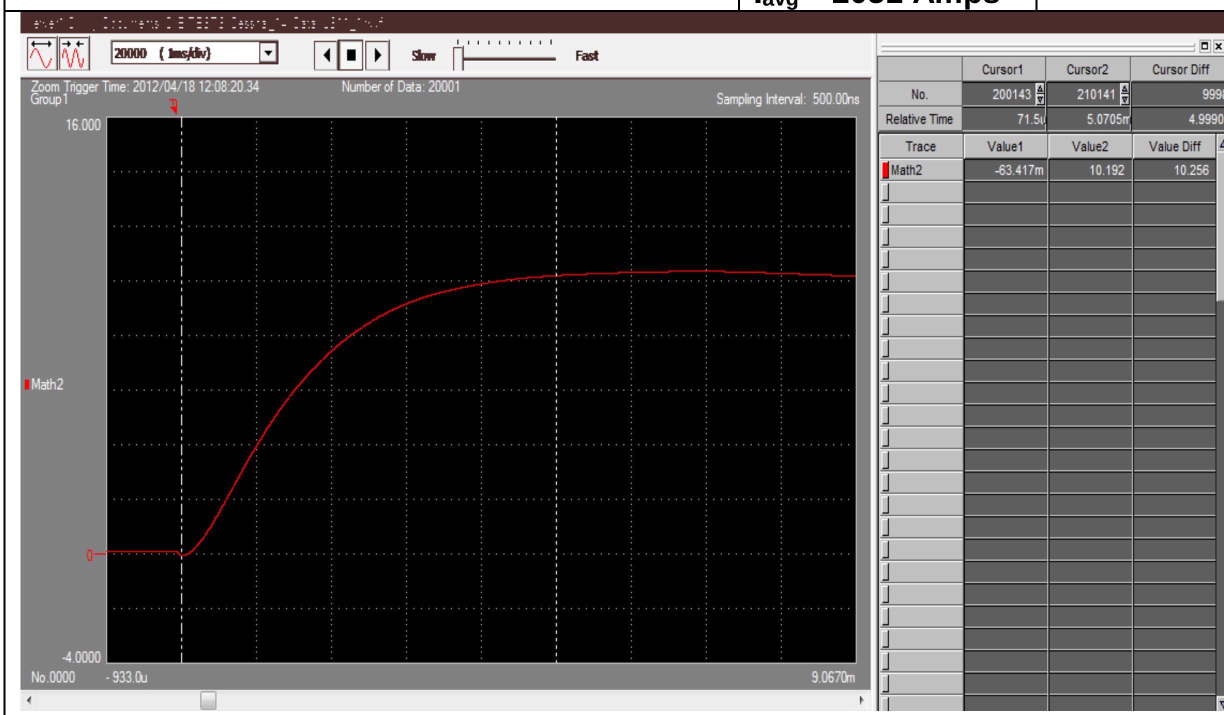


COMPONENT D ACTION INTEGRAL	AI = 262030 A^2-S

PANEL: LS-11

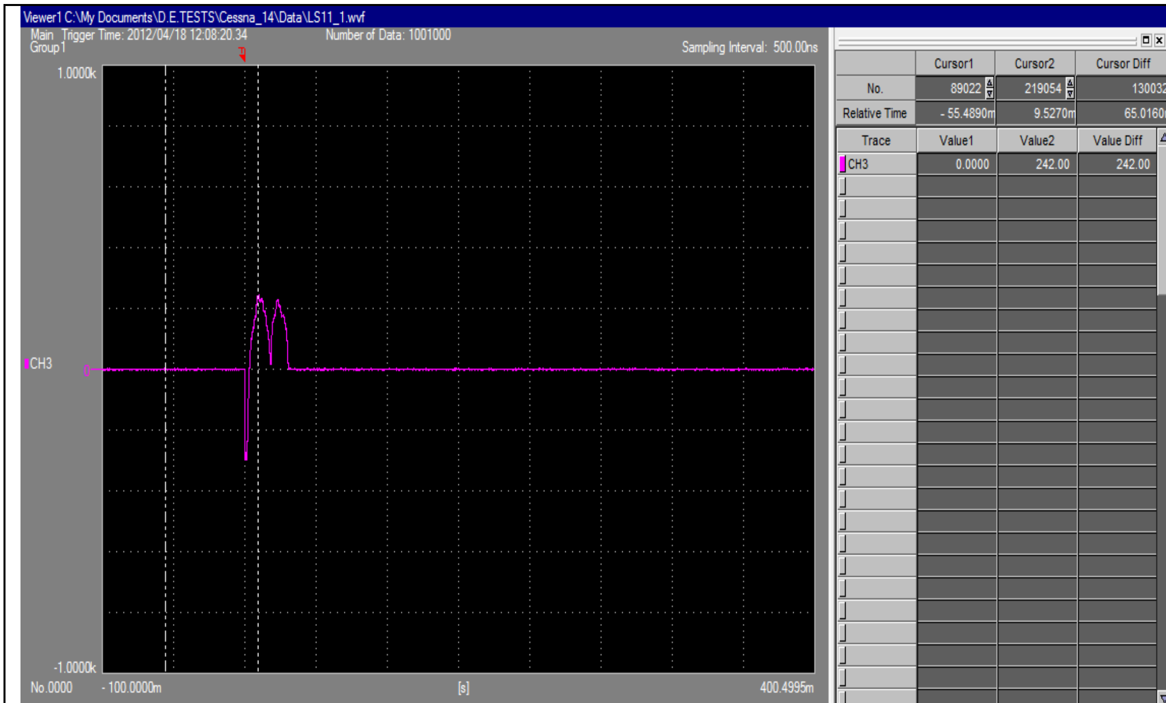


HIGH CURRENT – COMPONENT B	**I_P = 5000 Amps** **I_{avg} = 2051 Amps**	**1 mS / Div**

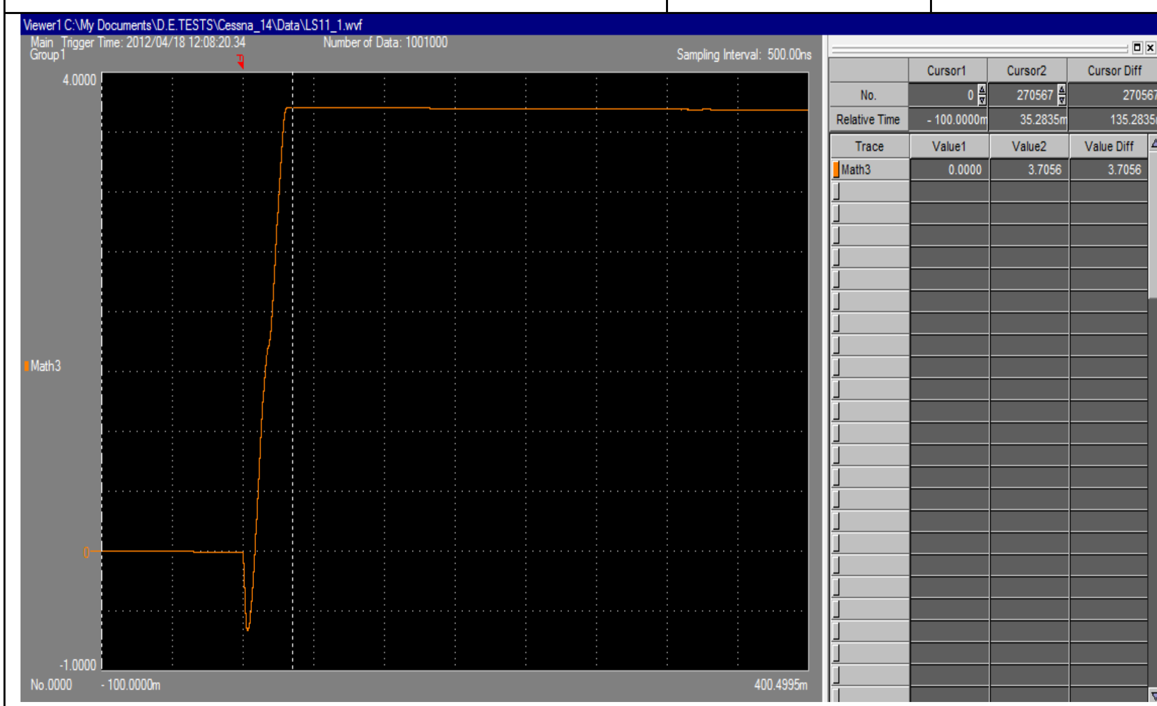


COMPONENT B CHARGE TRANSFER	**10.256 Coulombs**

PANEL: LS-11

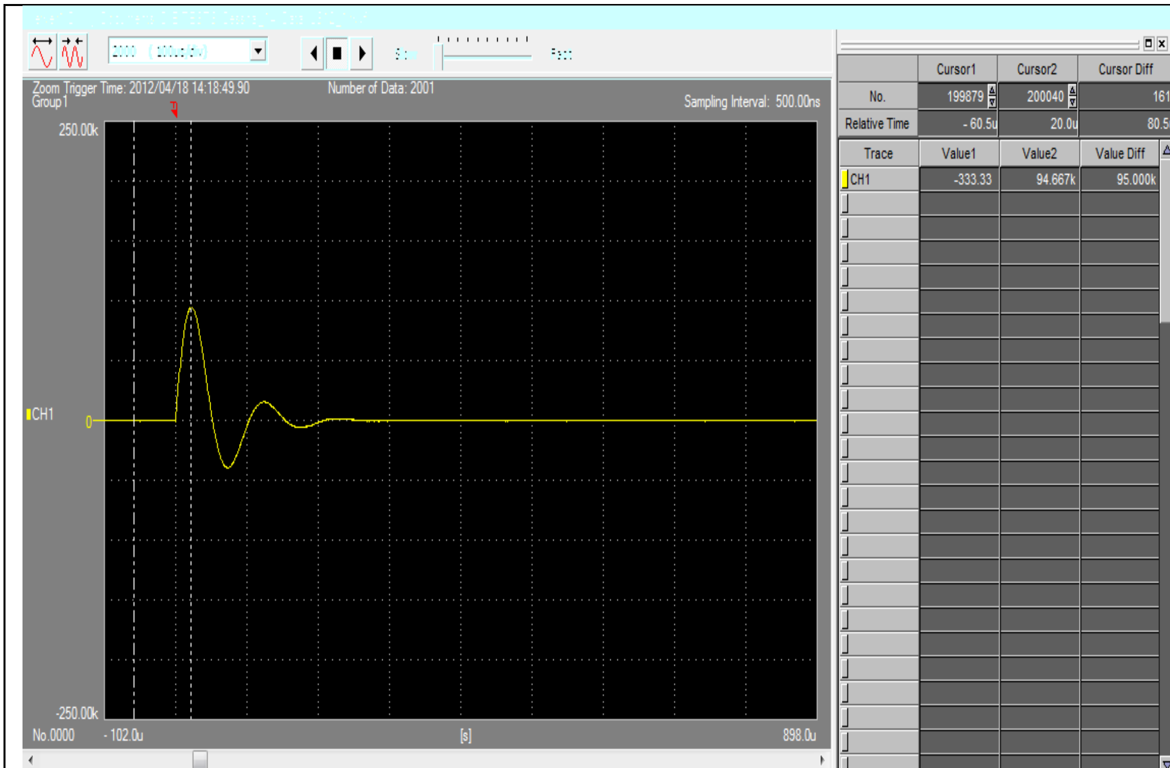


HIGH CURRENT – COMPONENT C*	Ip = 242 Amps	50 mS / Div

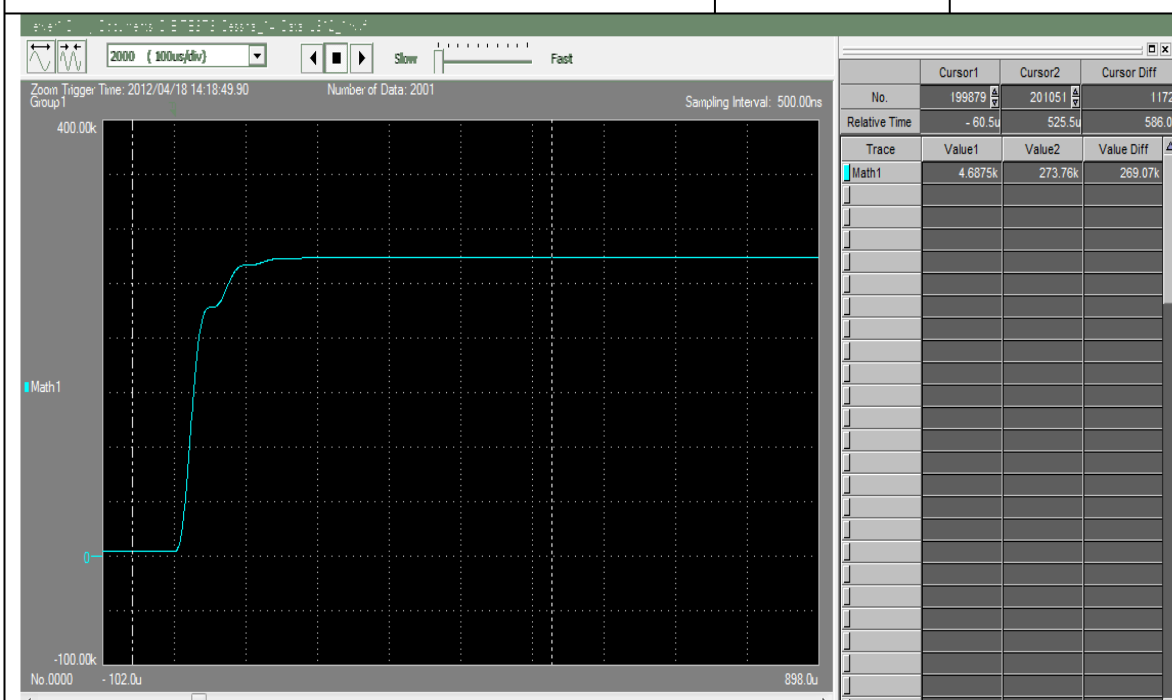


COMPONENT C* CHARGE TRANSFER	3.7 Coulombs

PANEL: LS-11

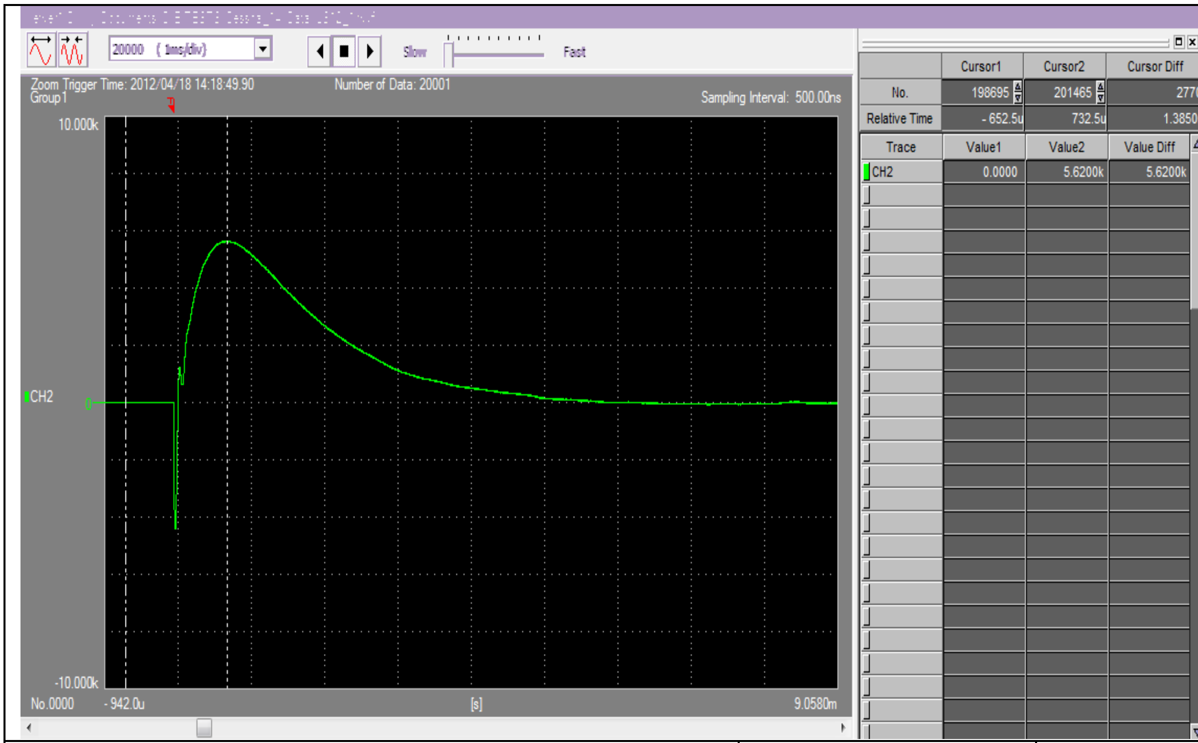


HIGH CURRENT – COMPONENT D	Ip = 95.0 KA	100 uS / Div

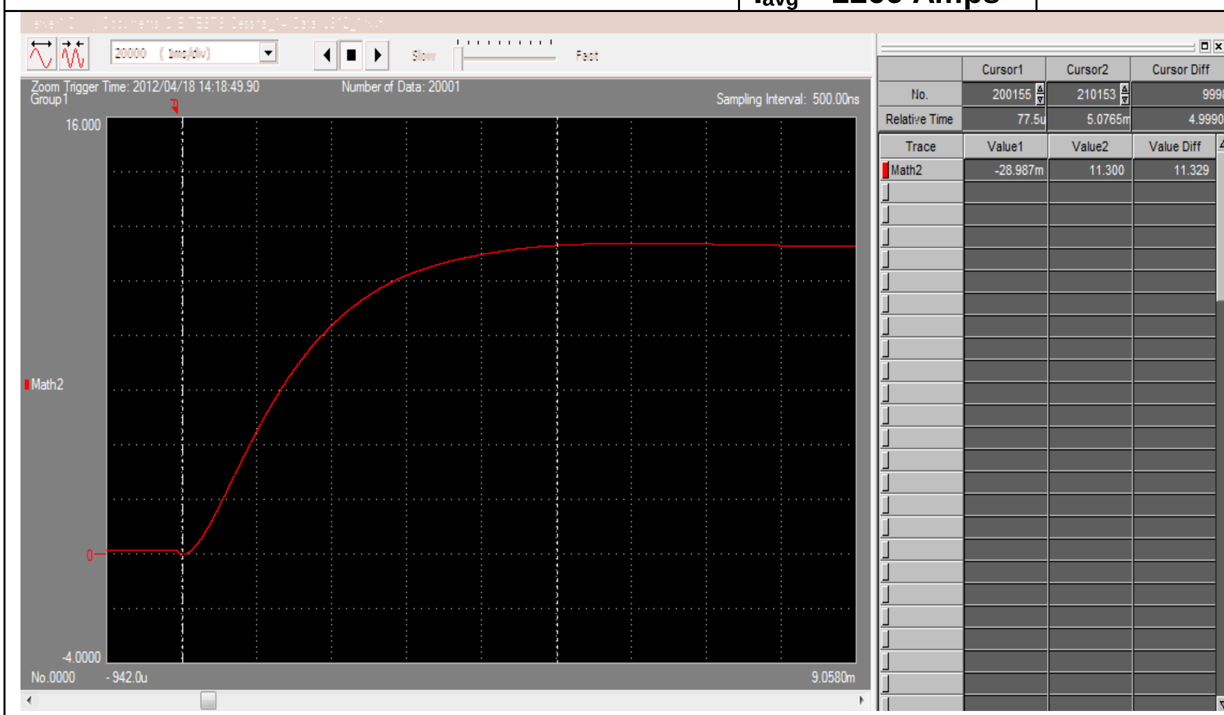


COMPONENT D ACTION INTEGRAL	AI = 269070 A^2-S

PANEL: LS-12

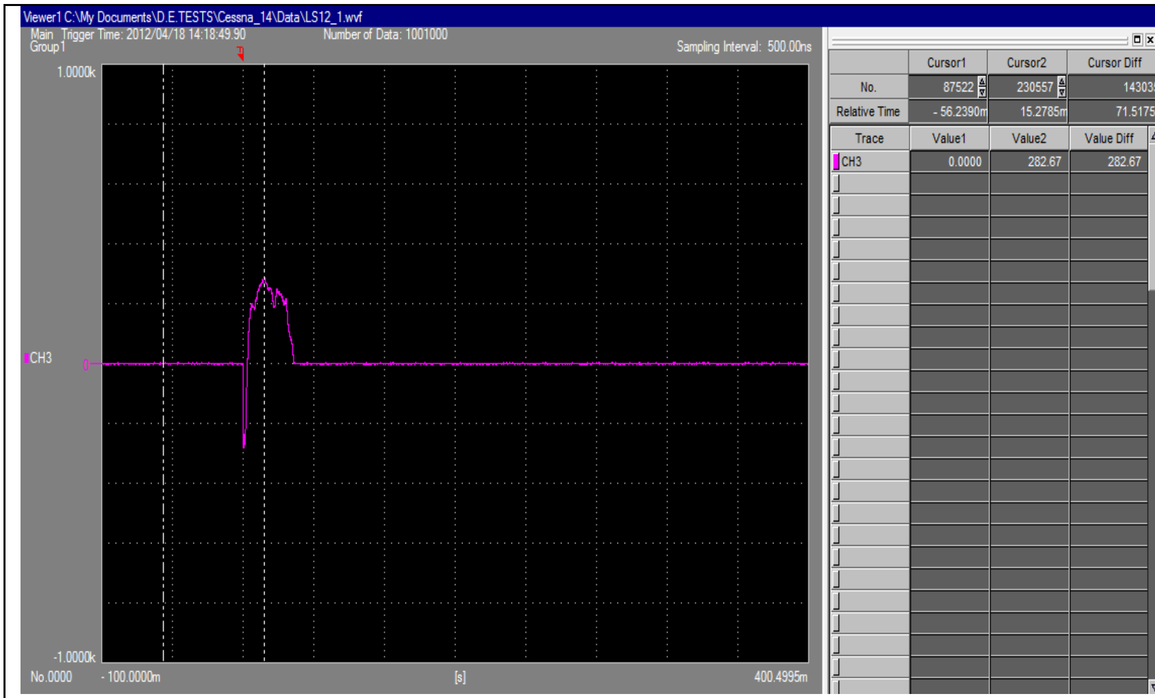


HIGH CURRENT – COMPONENT B	I_P = 5620 Amps I_{avg} = 2266 Amps	1 mS / Div

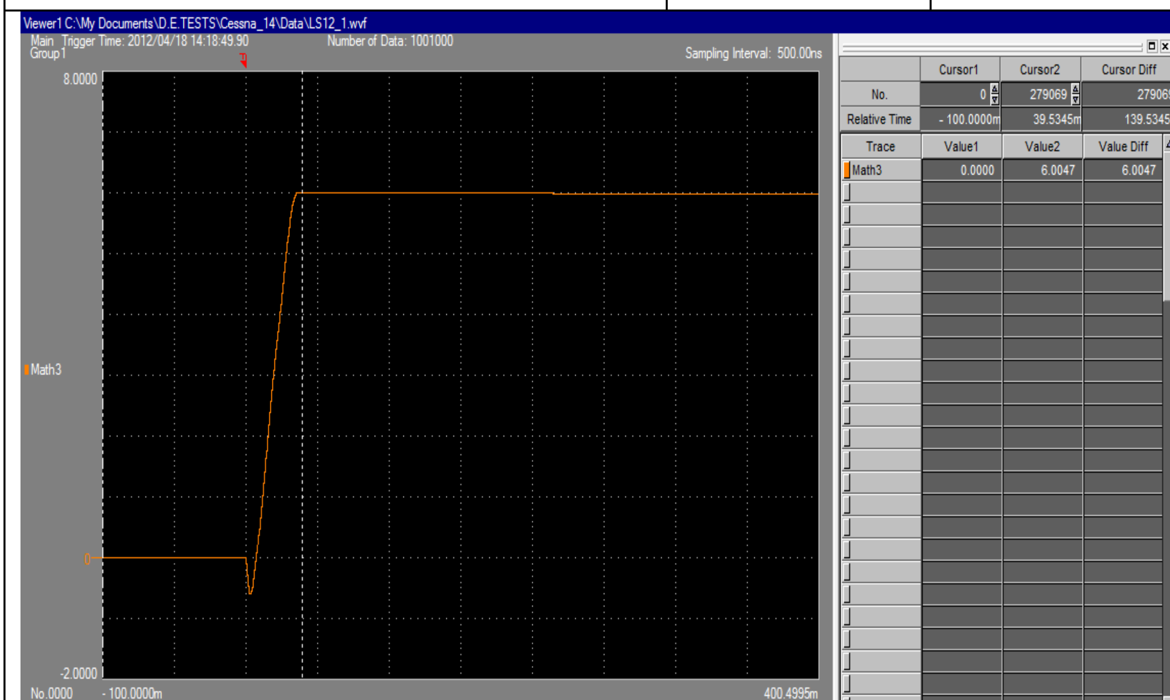


COMPONENT B CHARGE TRANSFER	11.329 Coulombs

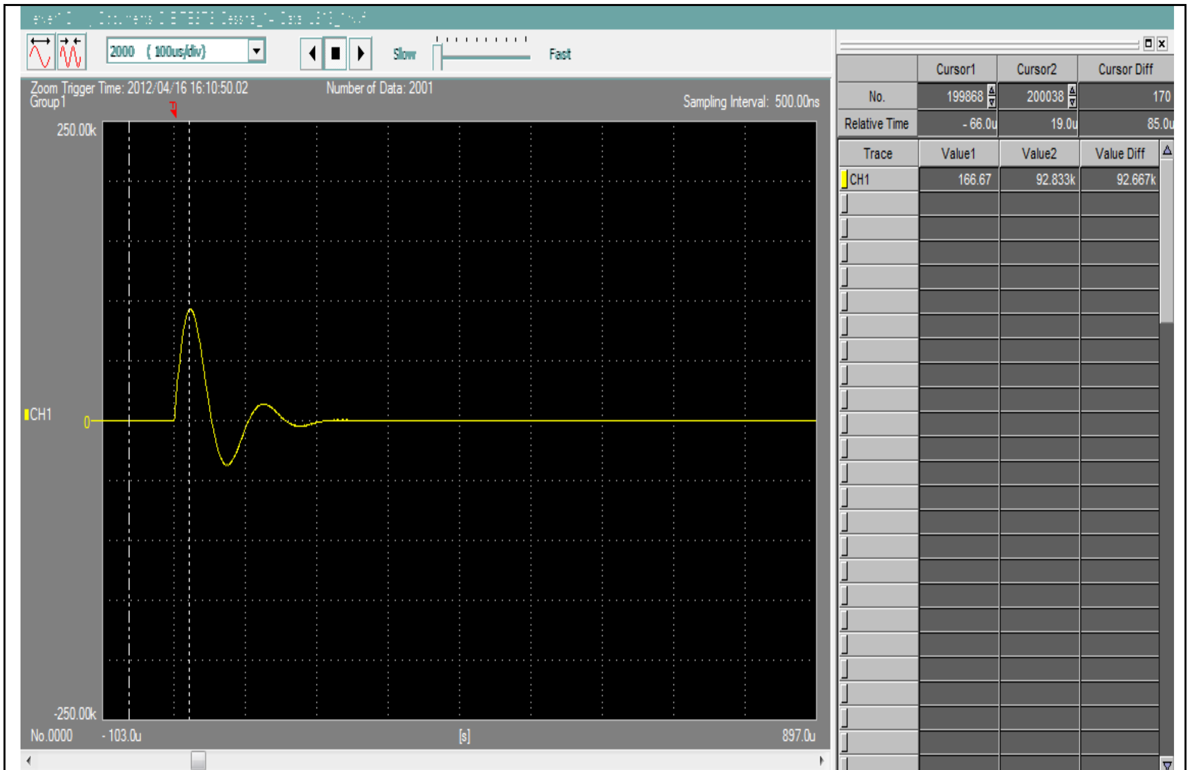
PANEL: LS-12



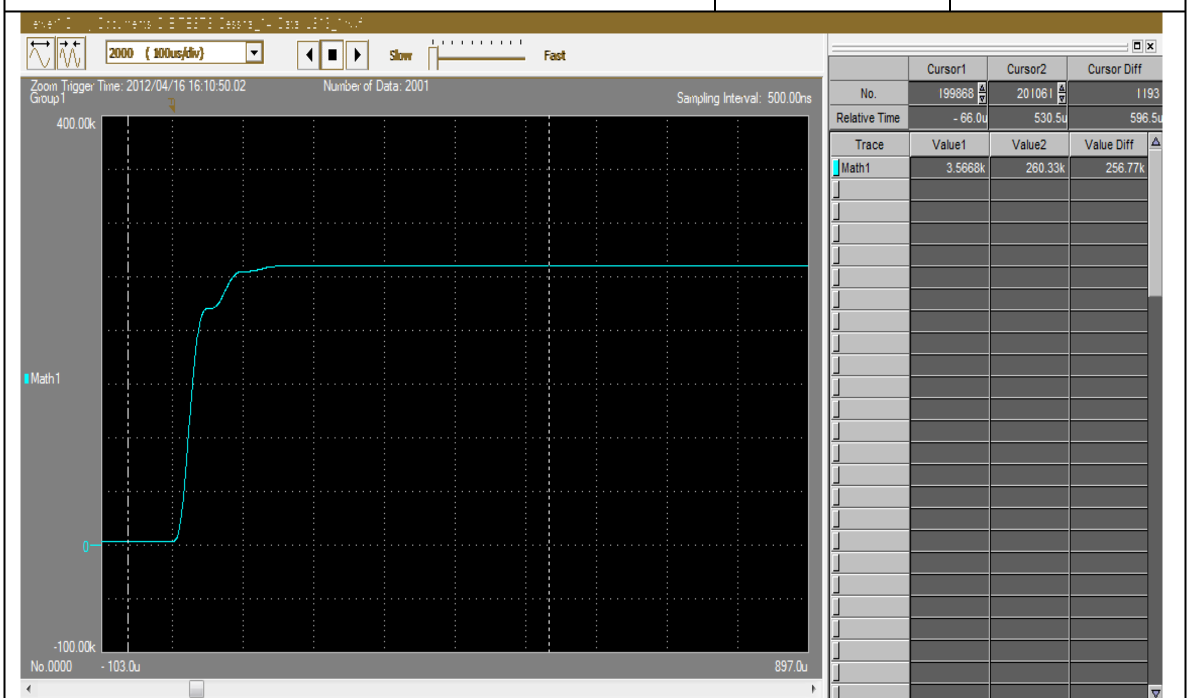
HIGH CURRENT – COMPONENT C*	**Ip = 283 Amps**	**50 mS / Div**



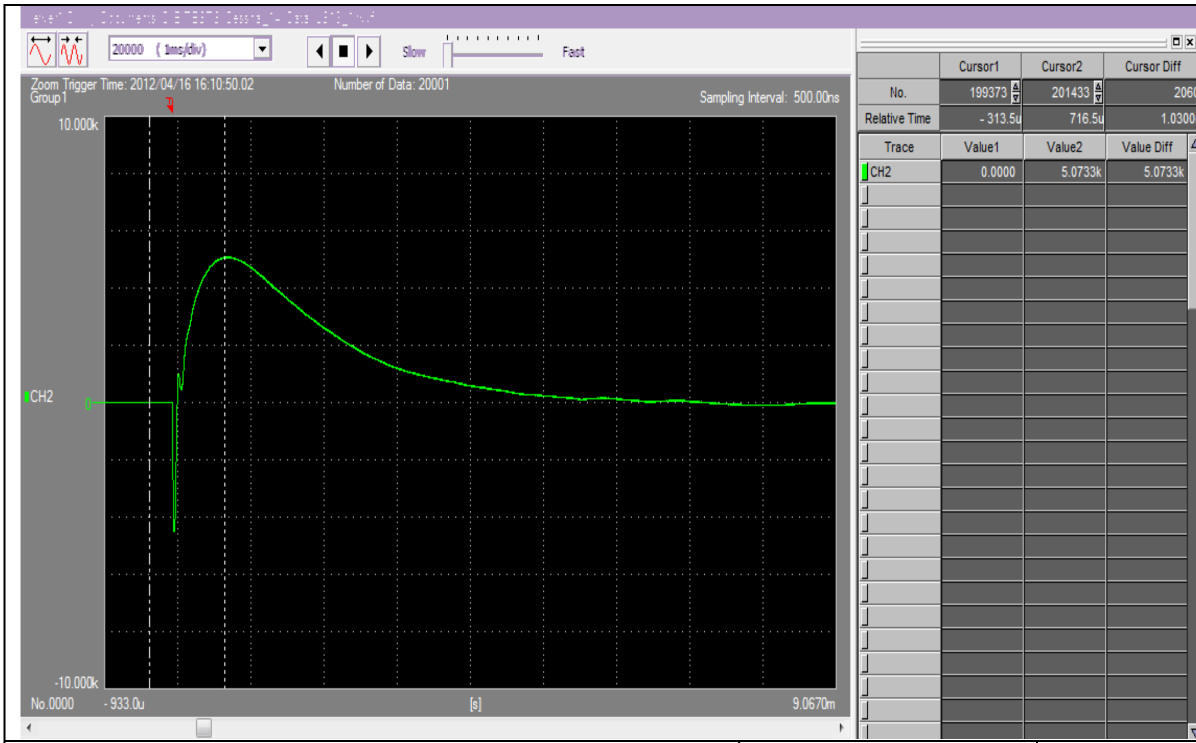
COMPONENT C* CHARGE TRANSFER	**6.0 Coulombs**
PANEL: LS-12	



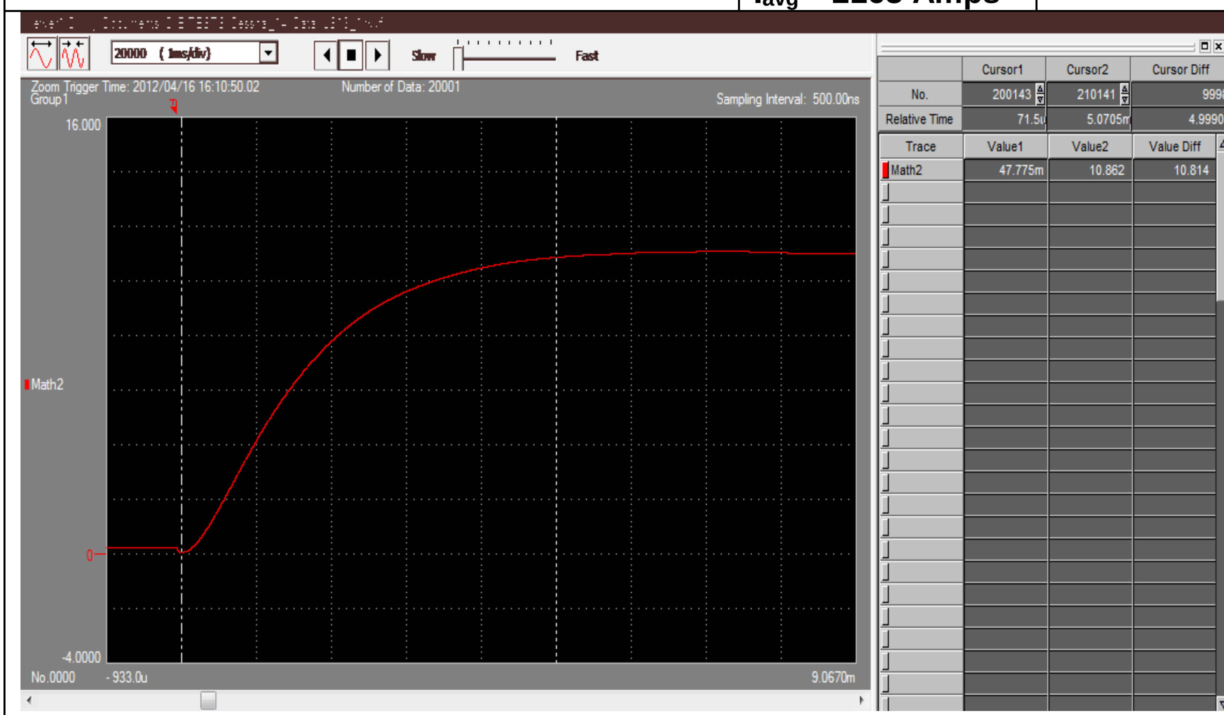
HIGH CURRENT – COMPONENT D	**Ip = 92.7 KA**	**100 uS / Div**



COMPONENT D ACTION INTEGRAL	**AI = 256770 A^2-S**
PANEL: LS-13	

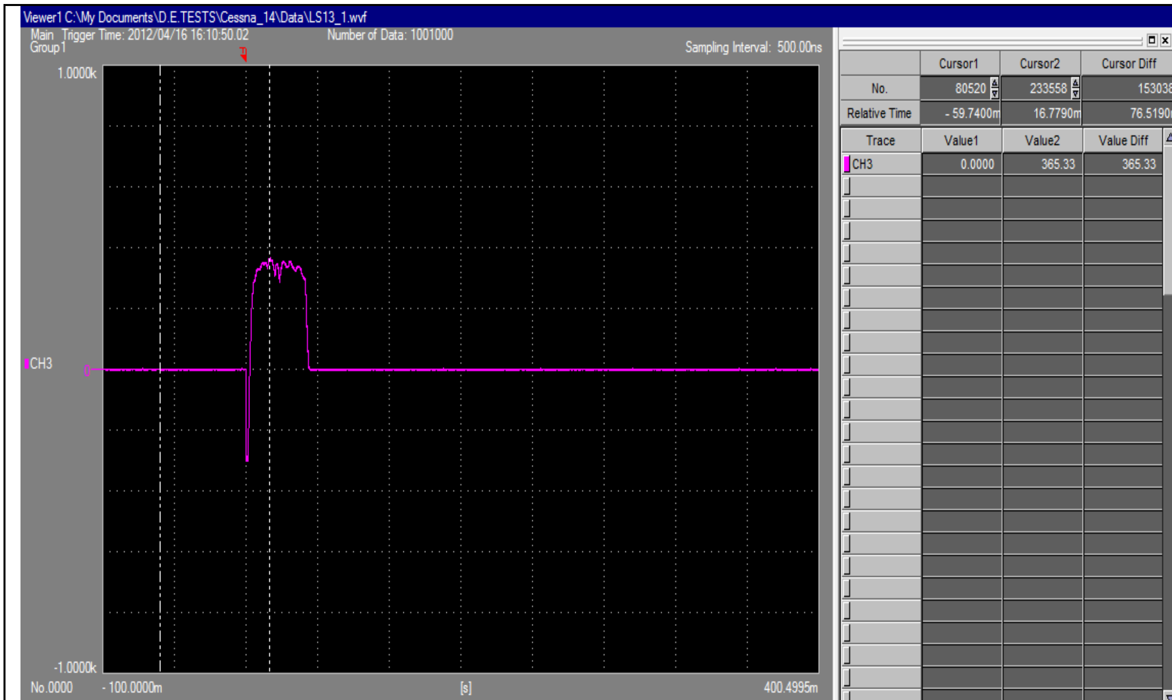


HIGH CURRENT – COMPONENT B	I_P = 5073 Amps I_{avg} = 2163 Amps	1 mS / Div

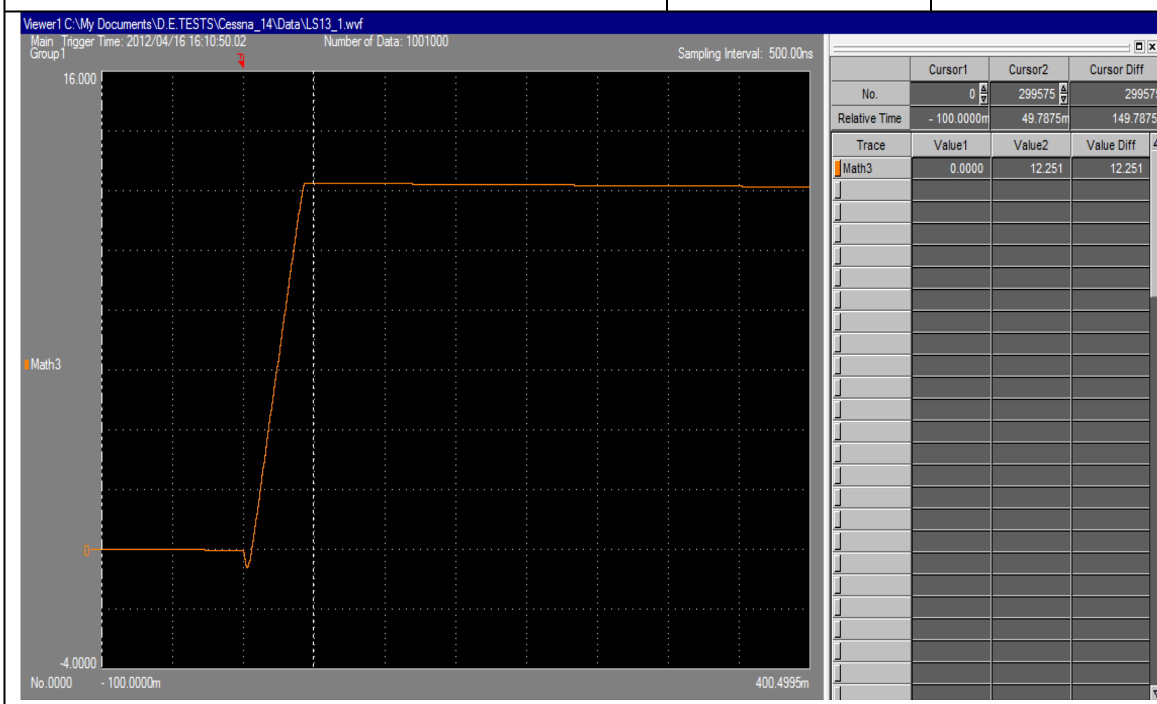


COMPONENT B CHARGE TRANSFER	10.814 Coulombs

PANEL: LS-13

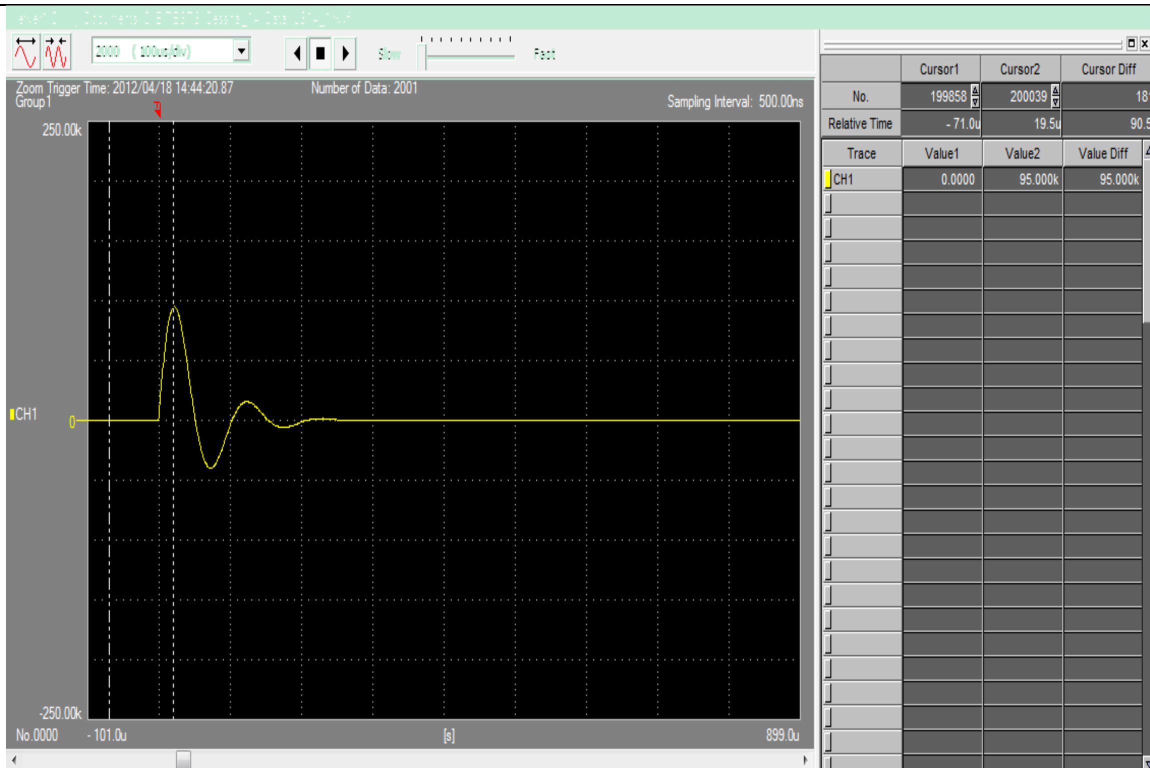


HIGH CURRENT – COMPONENT C*	Ip = 365 Amps	50 mS / Div

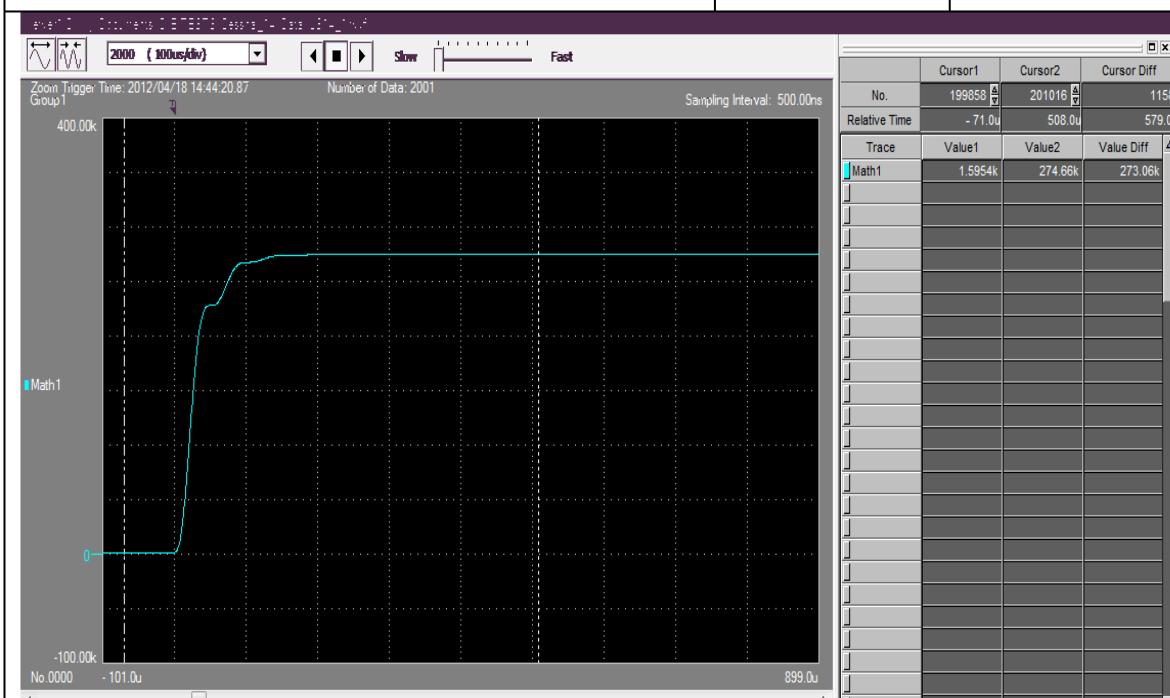


COMPONENT C* CHARGE TRANSFER	12.3 Coulombs

PANEL: LS-13

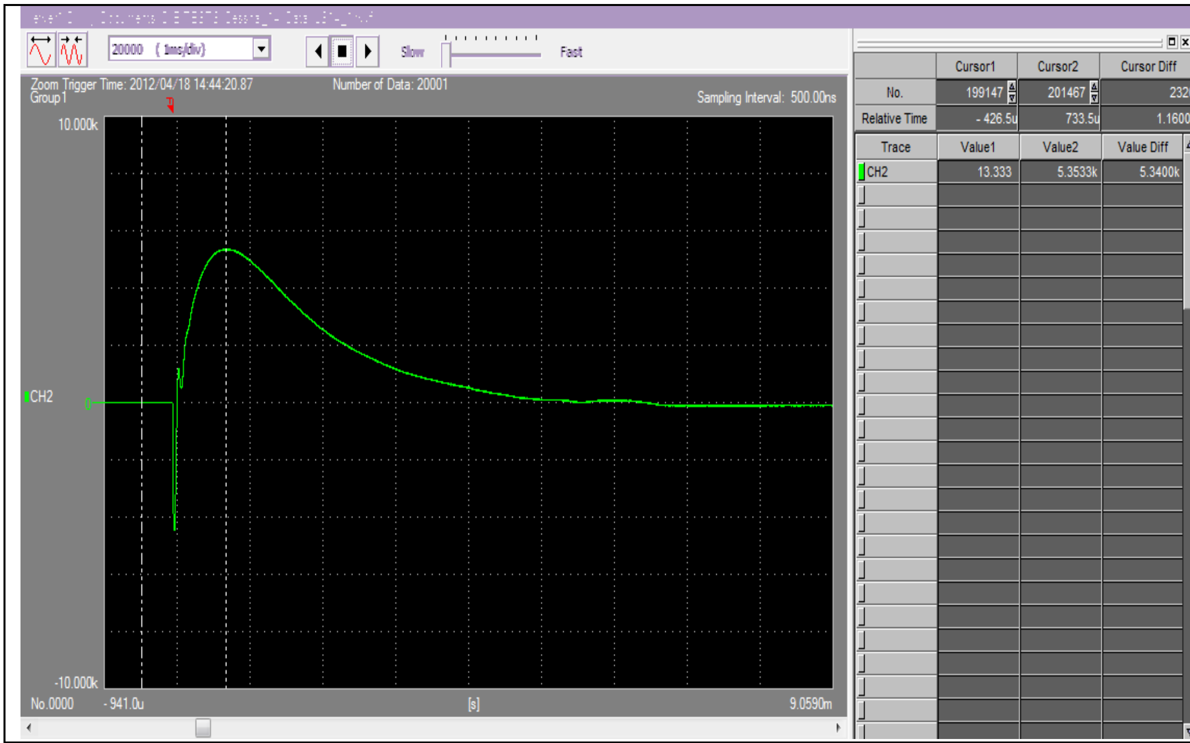


HIGH CURRENT – COMPONENT D	Ip = 95.0 KA	100 uS / Div

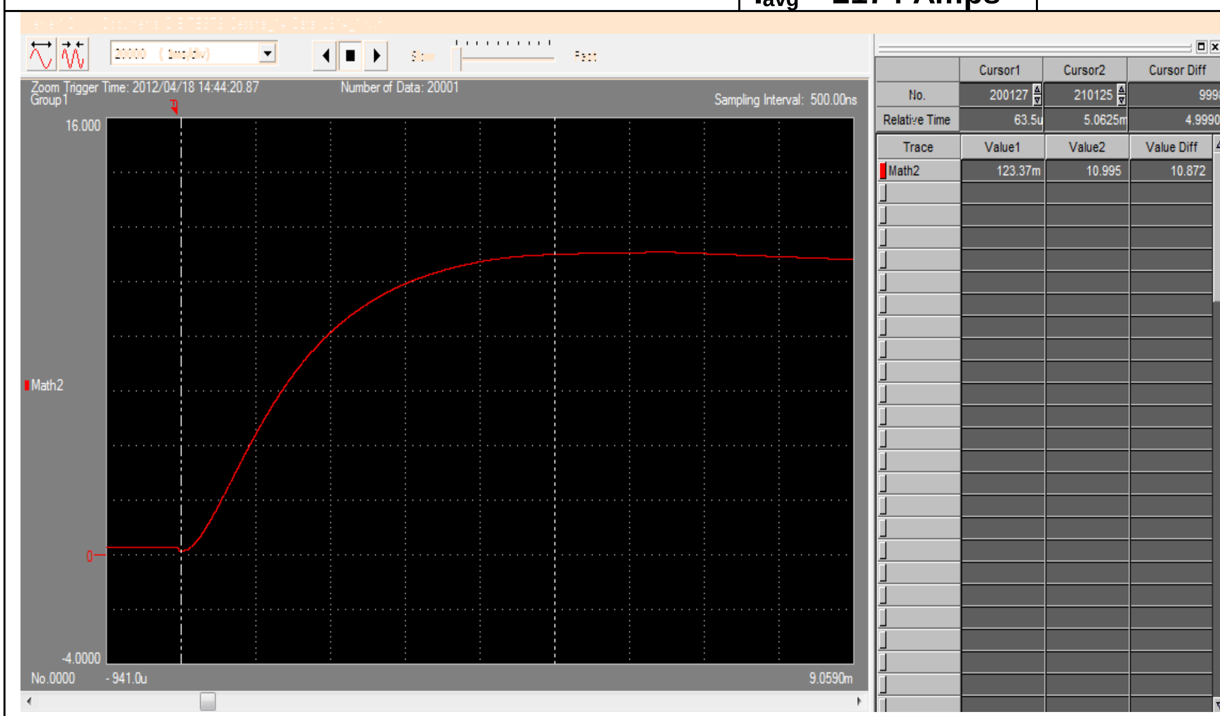


COMPONENT D ACTION INTEGRAL	AI = 273060 A^2-S

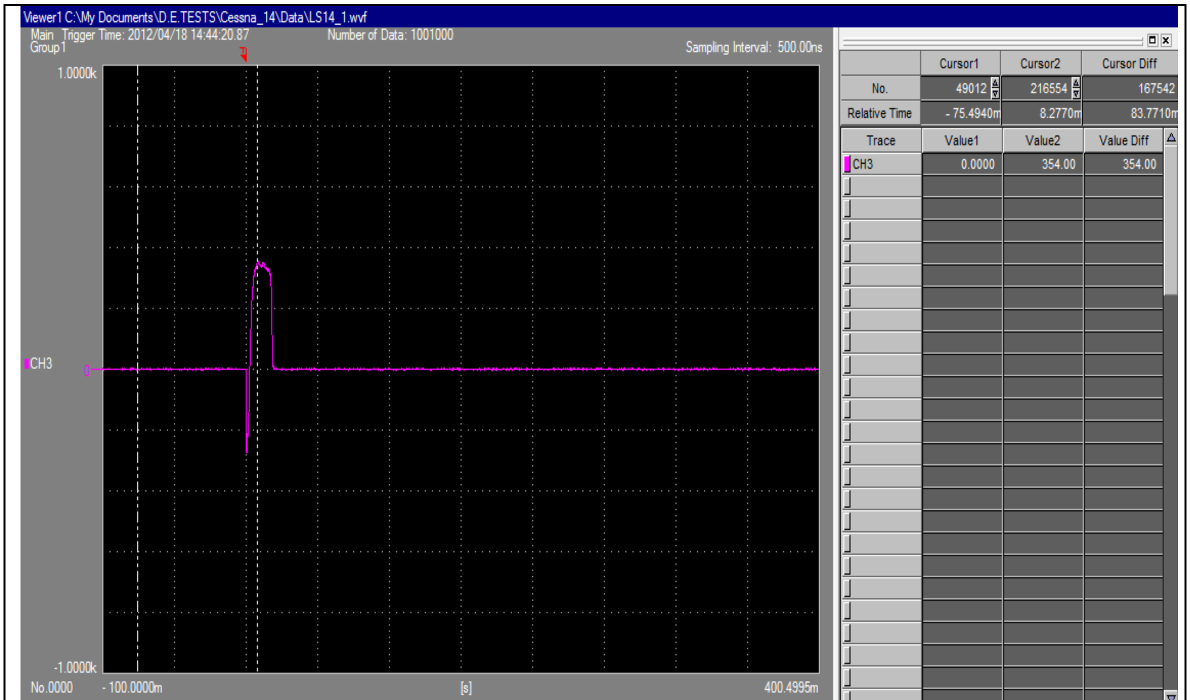
PANEL: LS-14



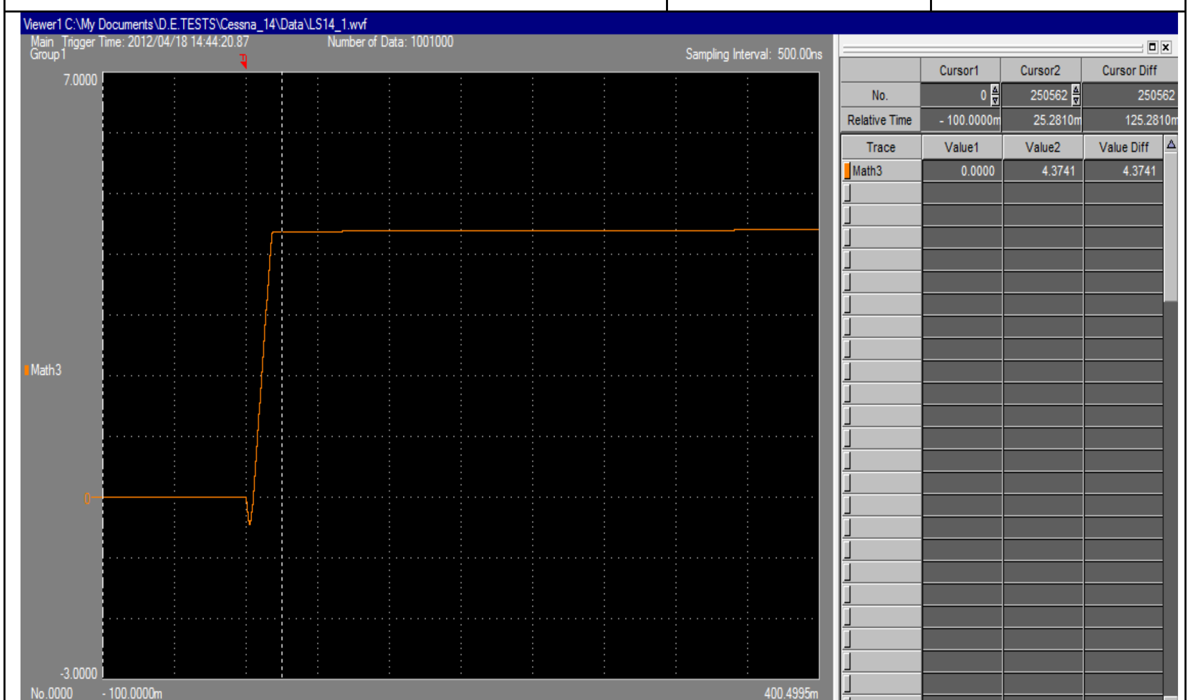
HIGH CURRENT – COMPONENT B	**I_P = 5340 Amps** **I_{avg} = 2174 Amps**	**1 mS / Div**



COMPONENT B CHARGE TRANSFER	**10.872 Coulombs**
PANEL: LS-14	

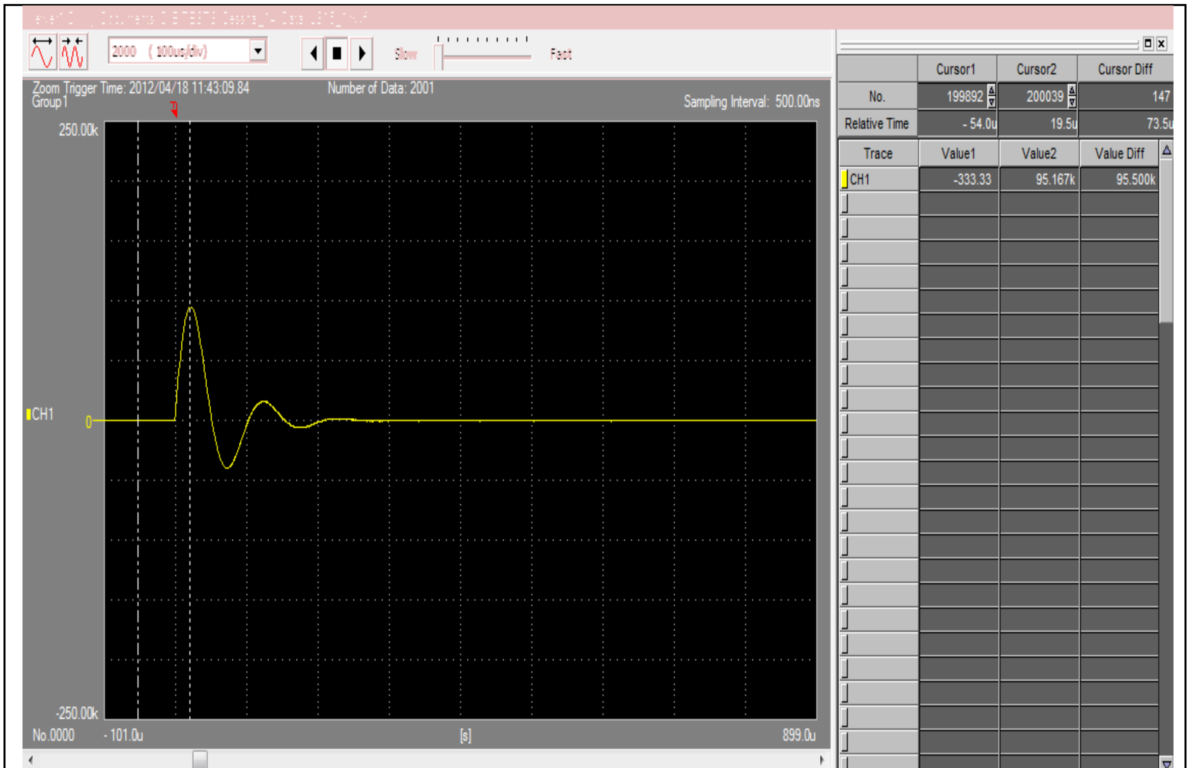


HIGH CURRENT – COMPONENT C*	Ip = 354 Amps	50 mS / Div

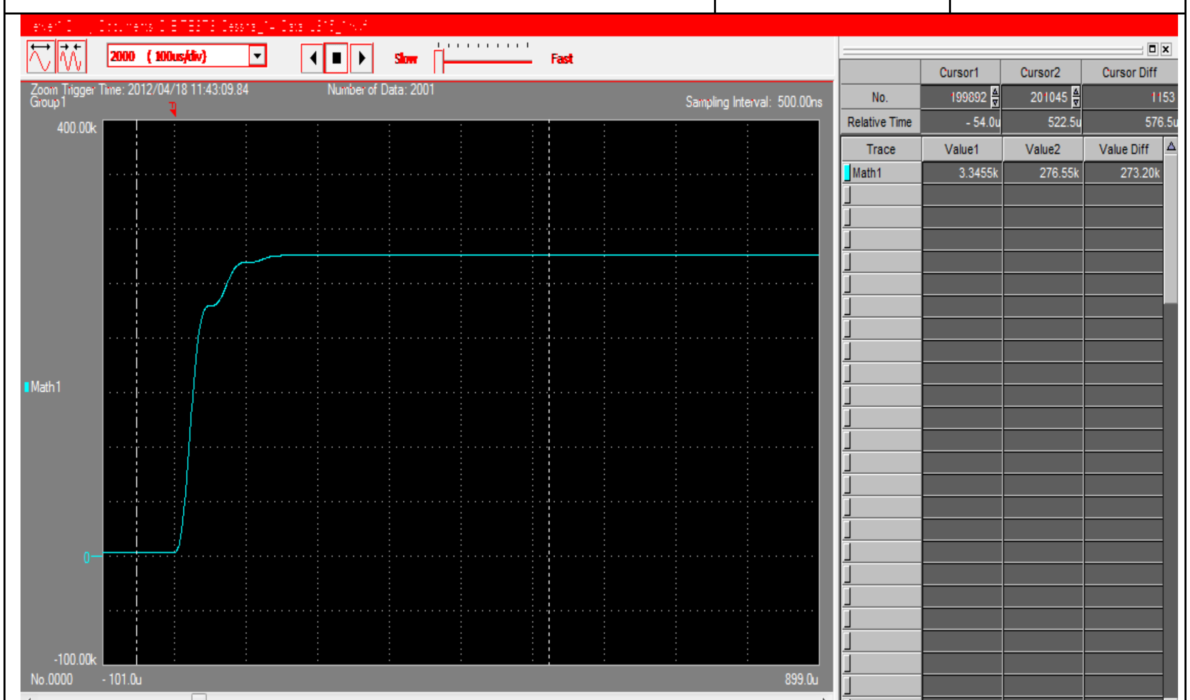


COMPONENT C* CHARGE TRANSFER	4.4 Coulombs

PANEL: LS-14

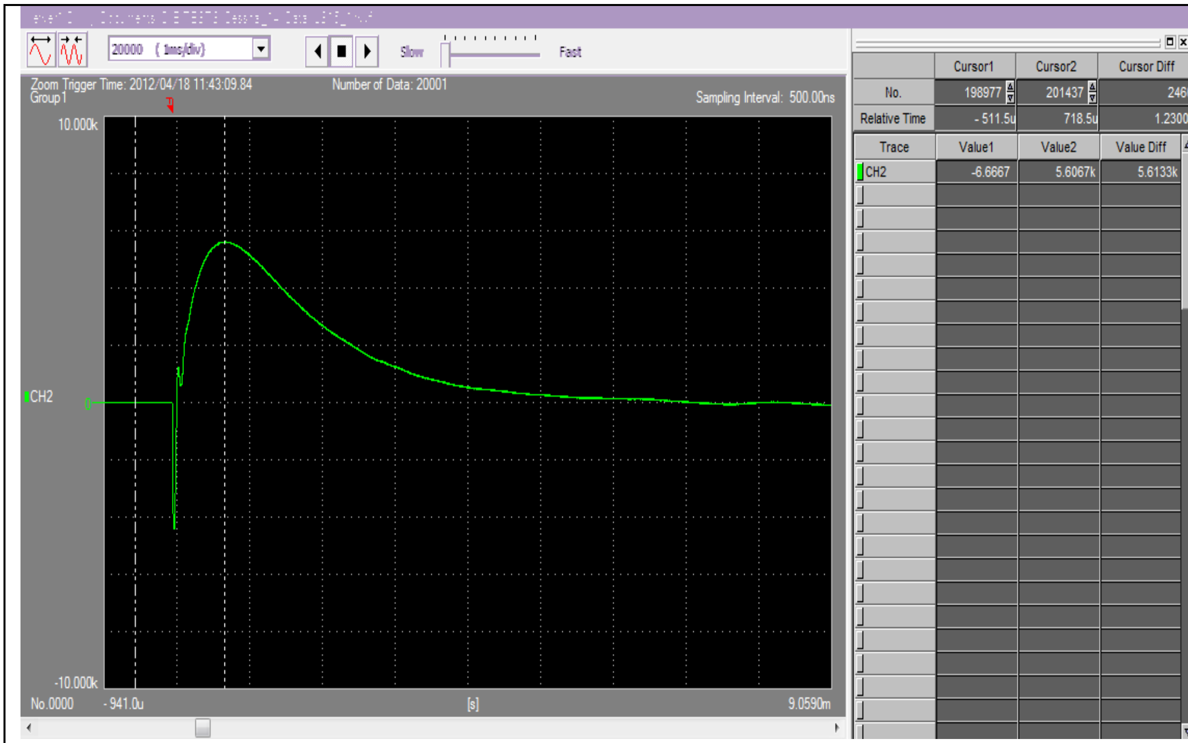


HIGH CURRENT – COMPONENT D	Ip = 95.5 KA	100 uS / Div

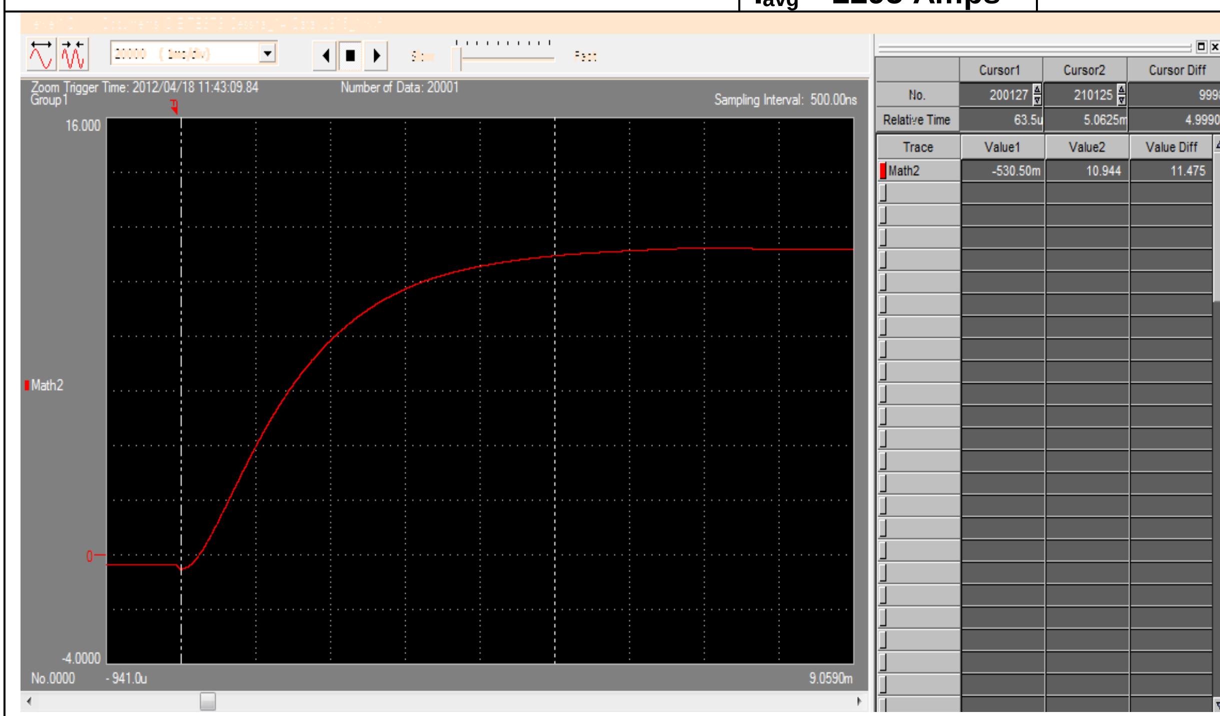


COMPONENT D ACTION INTEGRAL	AI = 273200 A^2-S

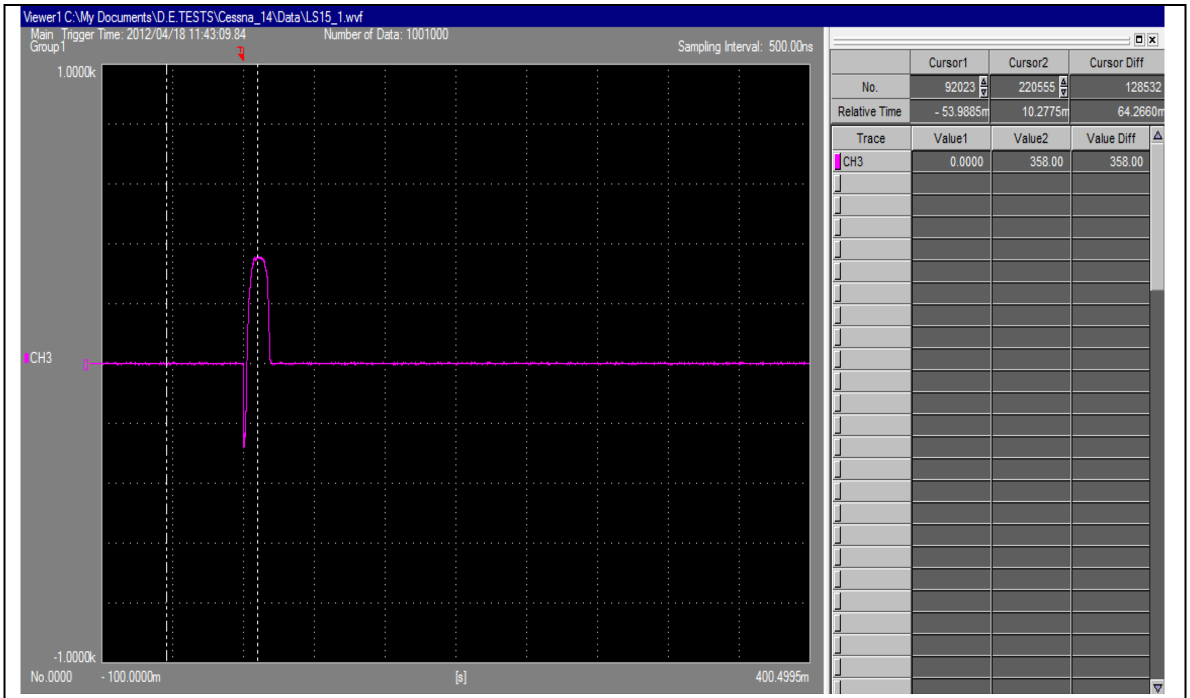
PANEL: LS-15



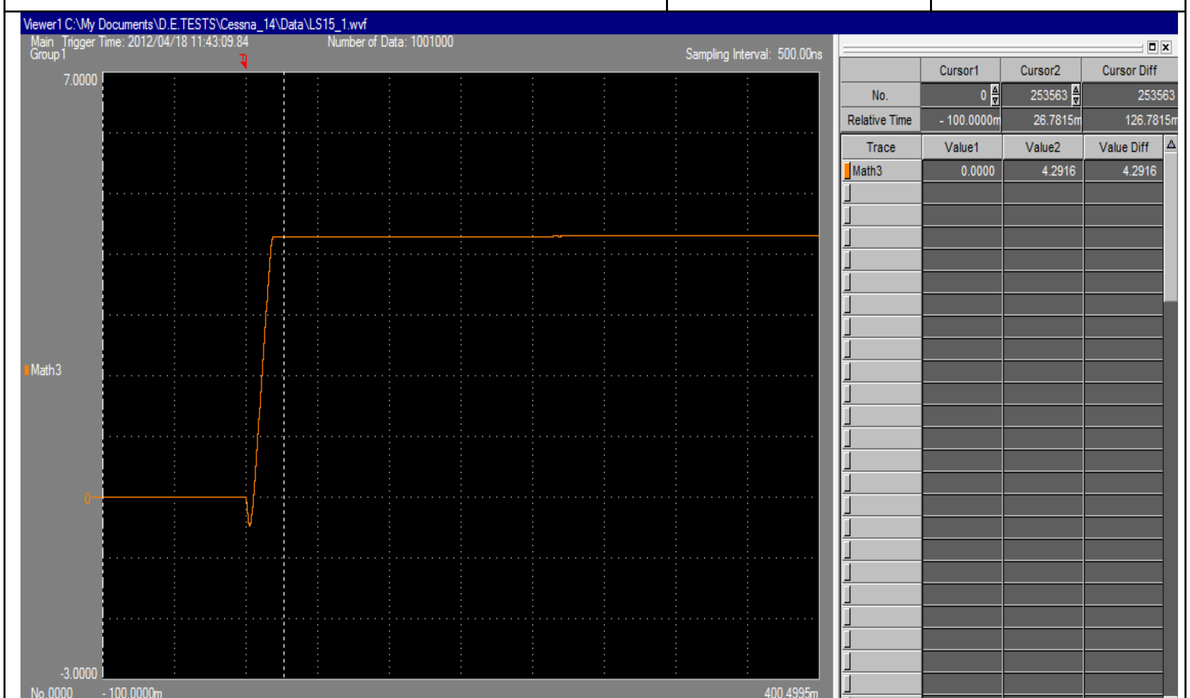
HIGH CURRENT – COMPONENT B	I_P = 5613 Amps I_{avg} = 2295 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.475 Coulombs
PANEL: LS-15	

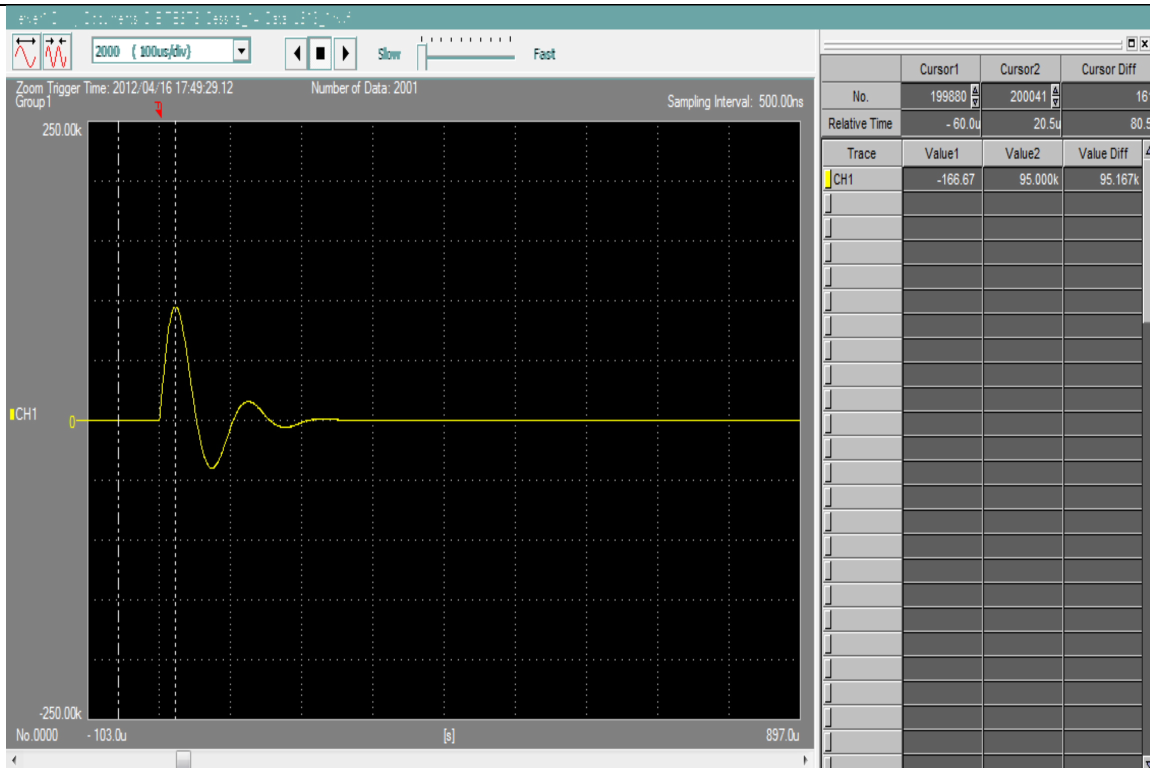


HIGH CURRENT – COMPONENT C*	Ip = 358 Amps	50 mS / Div

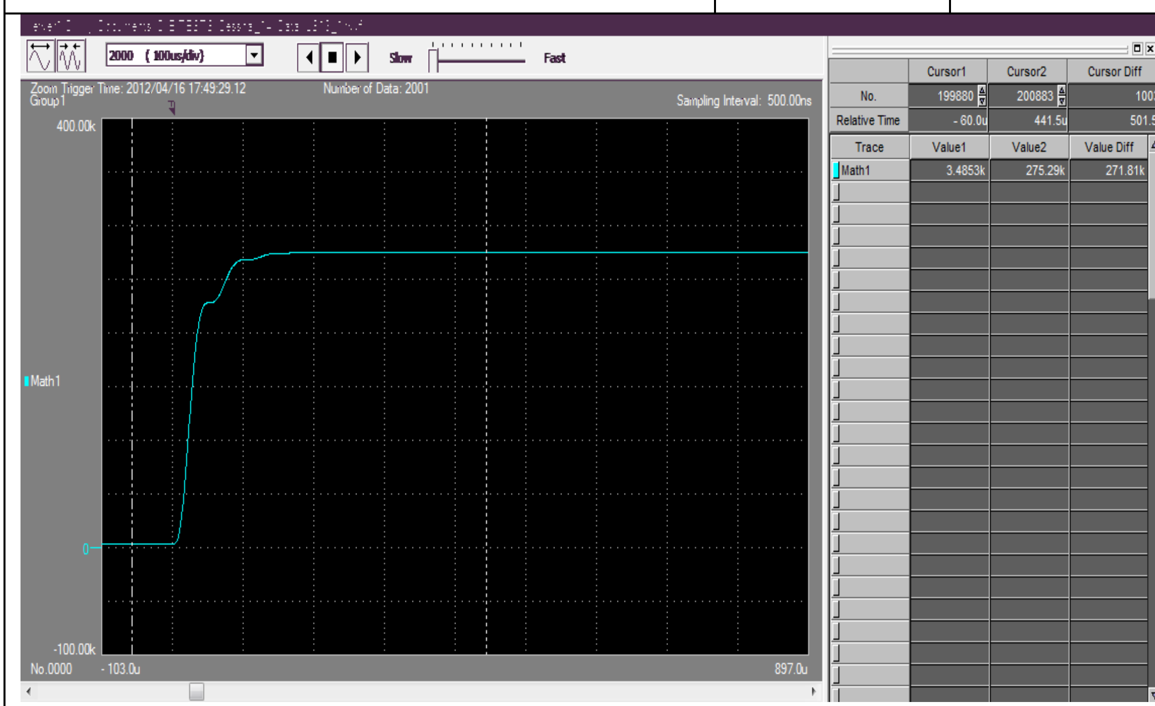


COMPONENT C* CHARGE TRANSFER	4.3 Coulombs

PANEL: LS-15

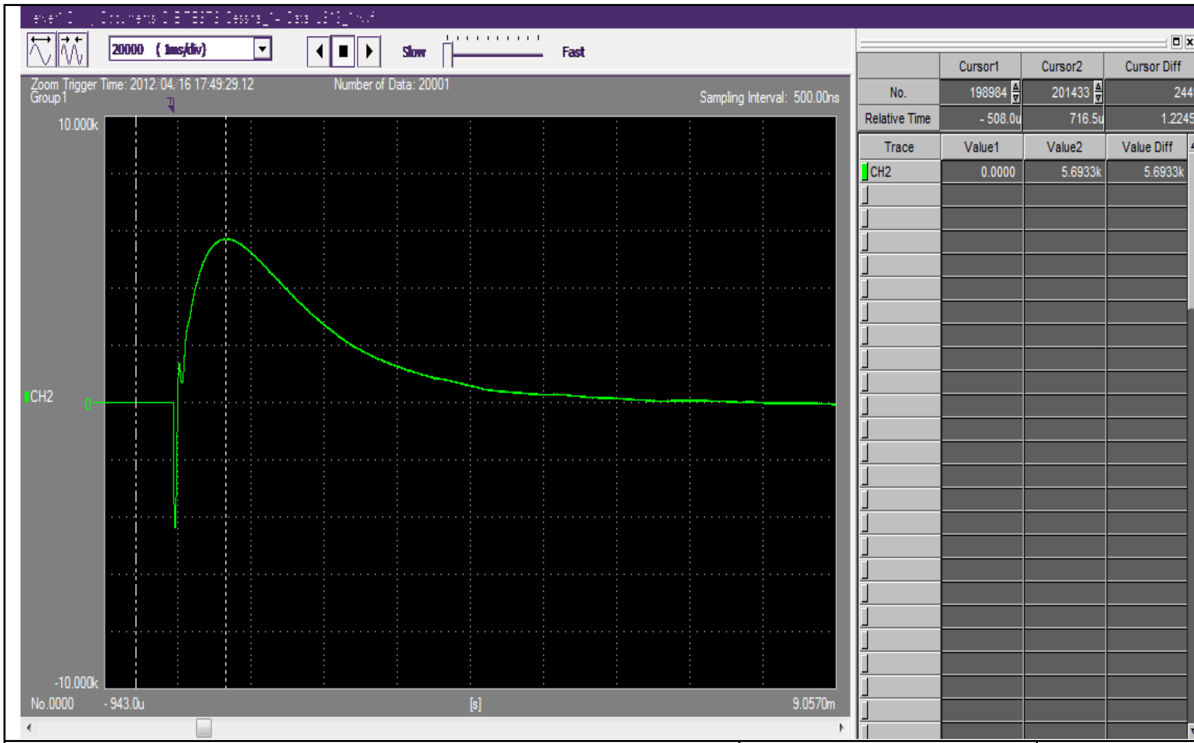


HIGH CURRENT – COMPONENT D	Ip = 95.2 KA	100 uS / Div

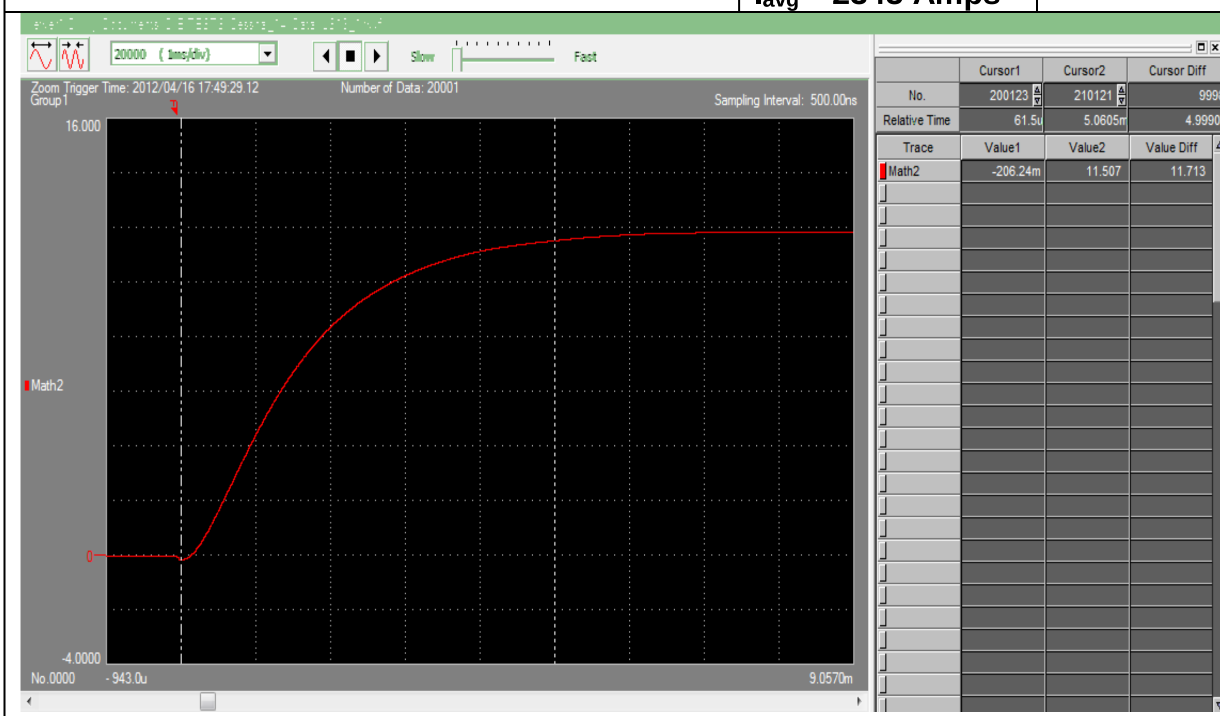


COMPONENT D ACTION INTEGRAL	AI = 271810 A^2-S

PANEL: LS-16



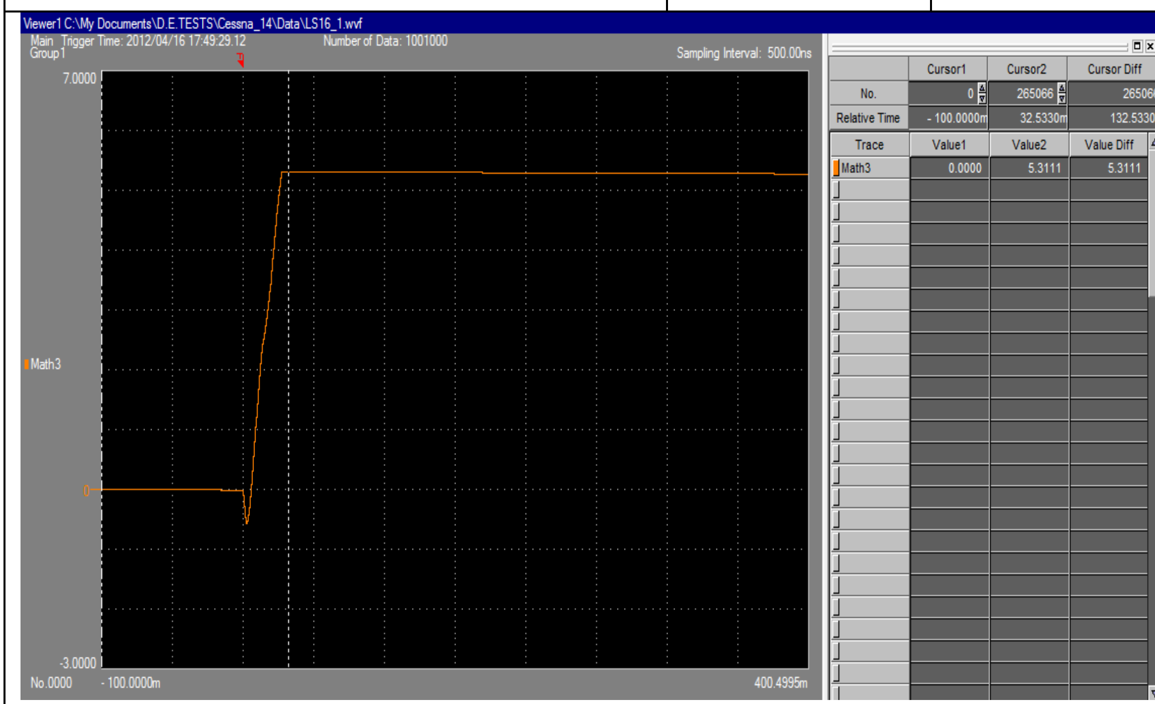
HIGH CURRENT – COMPONENT B	I_P = 5693 Amps I_{avg} = 2343 Amps	1 mS / Div



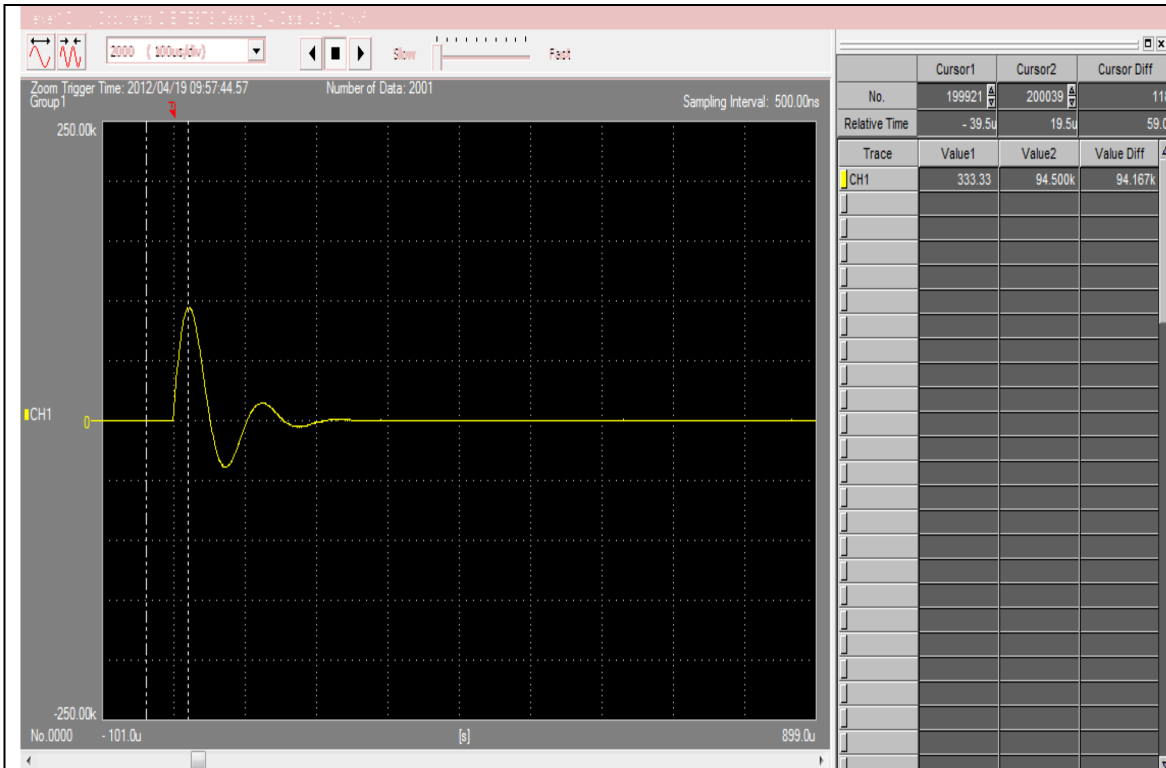
COMPONENT B CHARGE TRANSFER	11.713 Coulombs

PANEL: LS-16

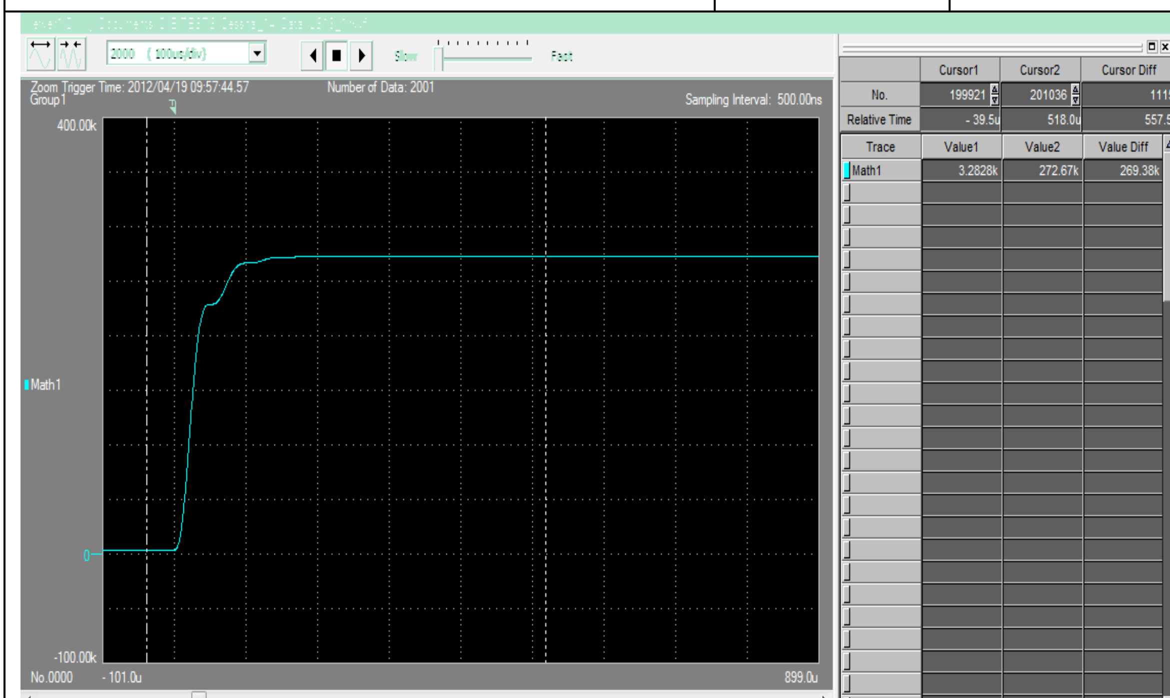
HIGH CURRENT – COMPONENT C*	Ip = 325 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	5.3 Coulombs
PANEL: LS-16	

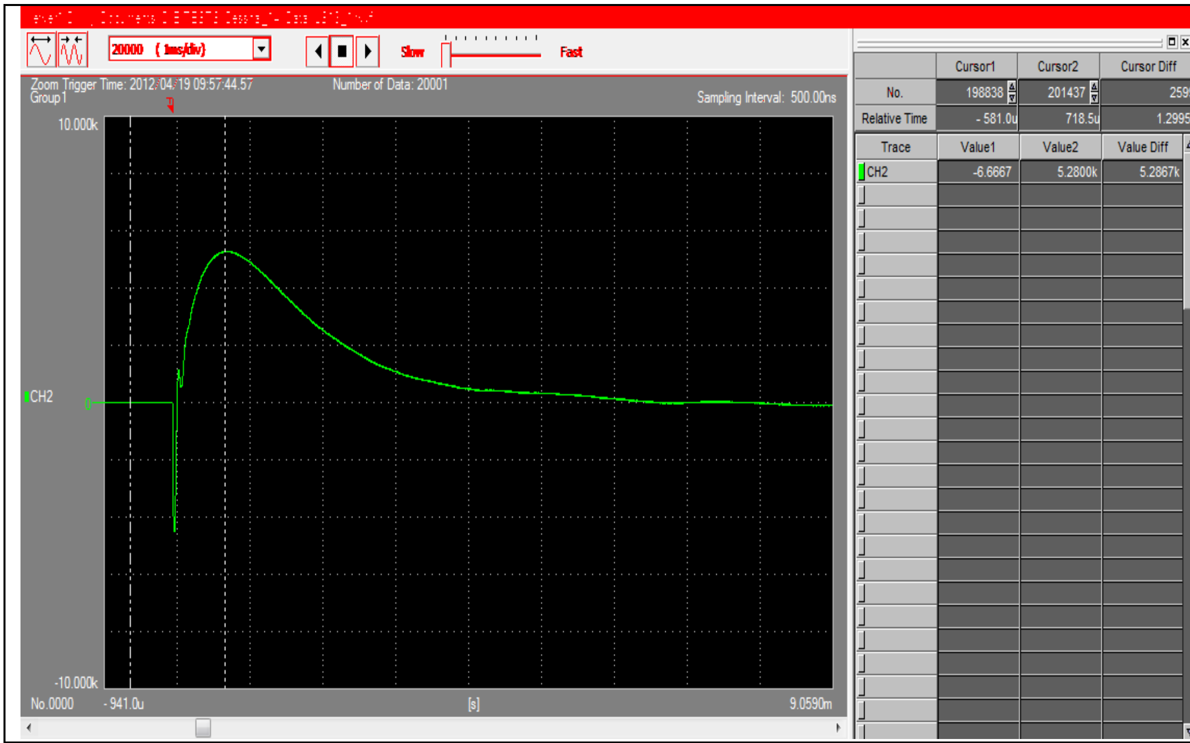


HIGH CURRENT – COMPONENT D	Ip = 94.2 KA	100 uS / Div

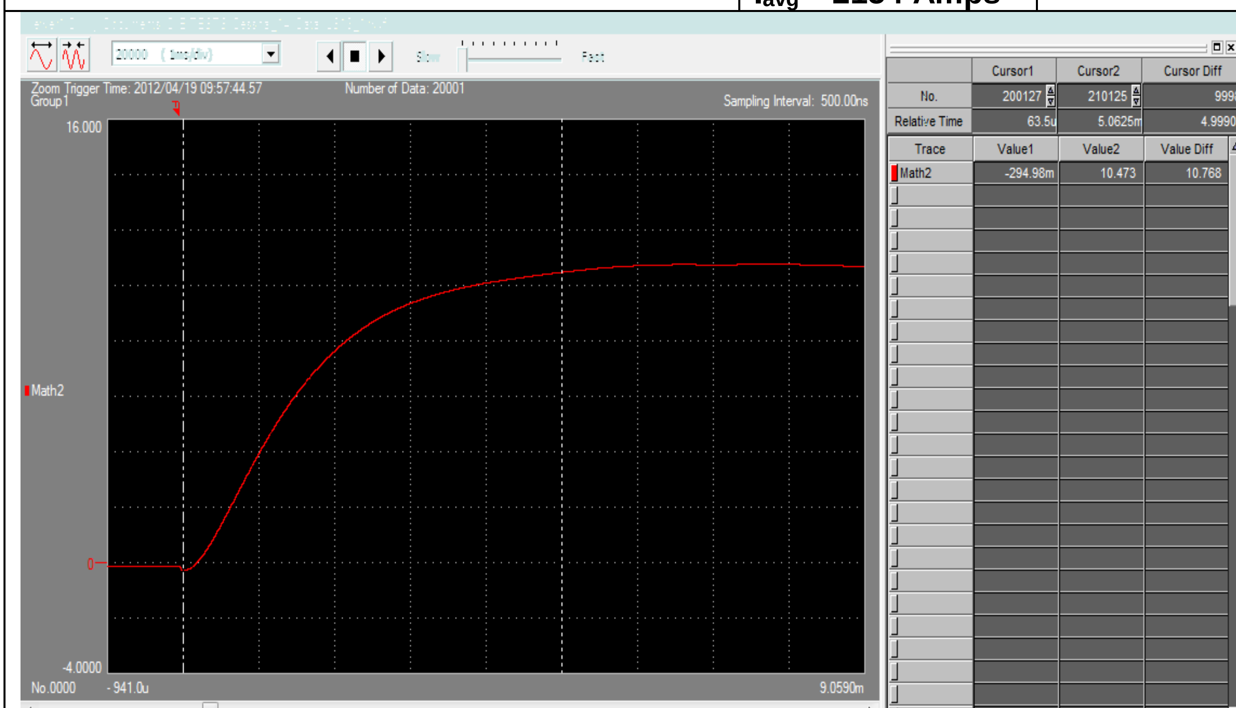


COMPONENT D ACTION INTEGRAL	AI = 269380 A^2-S

PANEL: LS-18

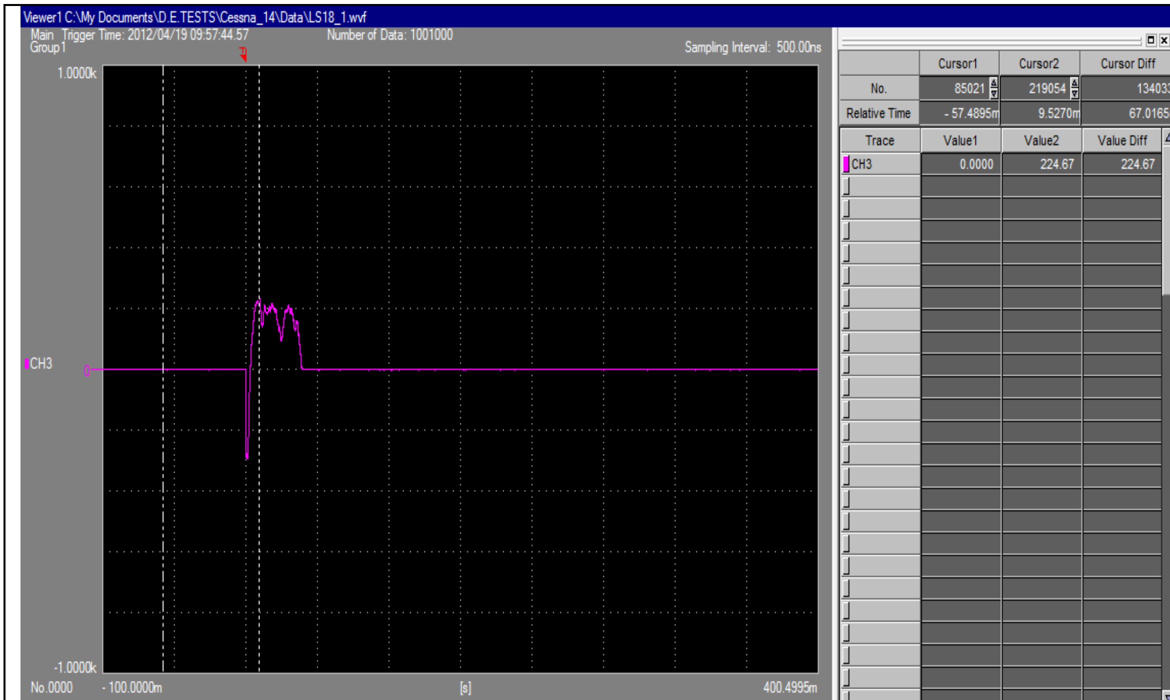


HIGH CURRENT – COMPONENT B	**I_P = 5287 Amps** **I_{avg} = 2154 Amps**	**1 mS / Div**



COMPONENT B CHARGE TRANSFER	**10.768 Coulombs**

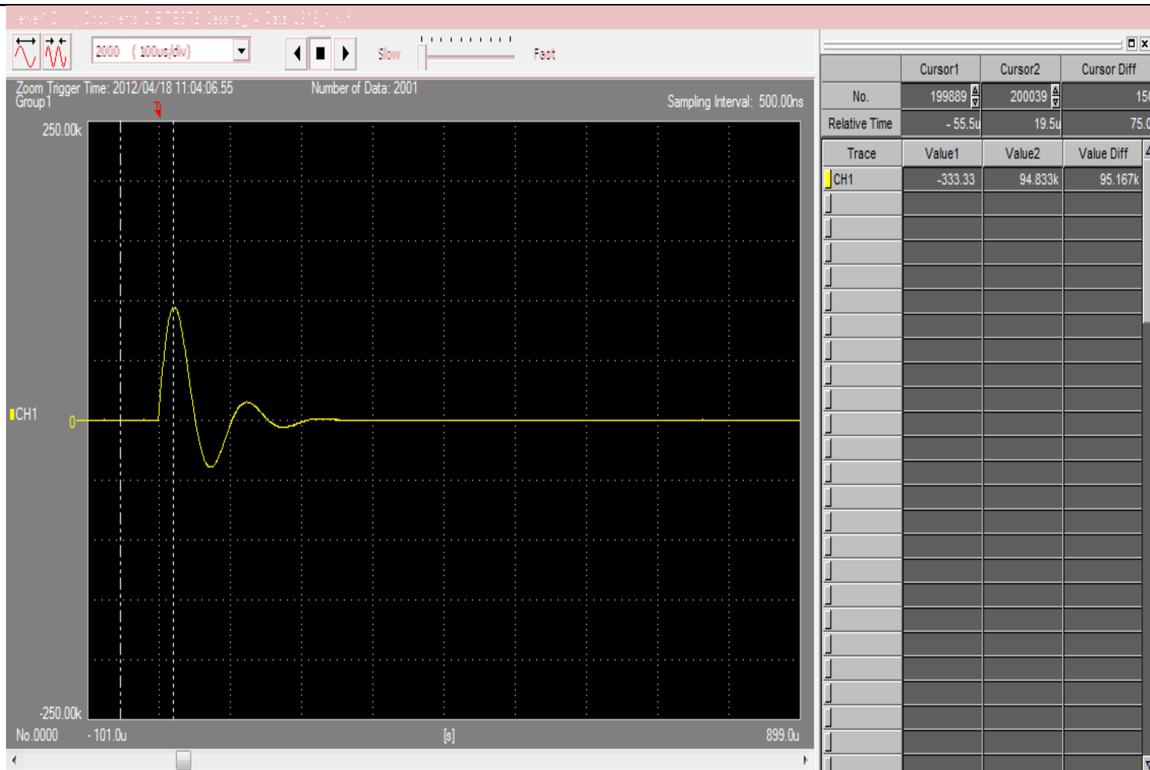
PANEL: LS-18



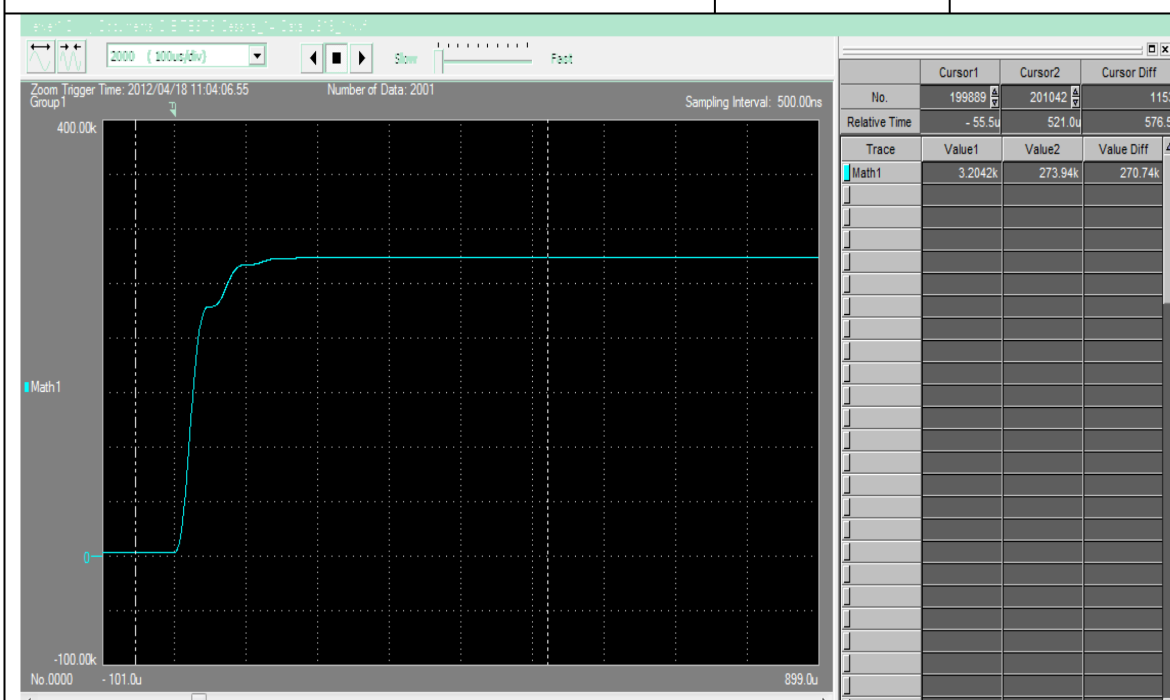
HIGH CURRENT – COMPONENT C*	**Ip = 225 Amps**	**50 mS / Div**

COMPONENT C* CHARGE TRANSFER	**5.4 Coulombs**

PANEL: LS-18

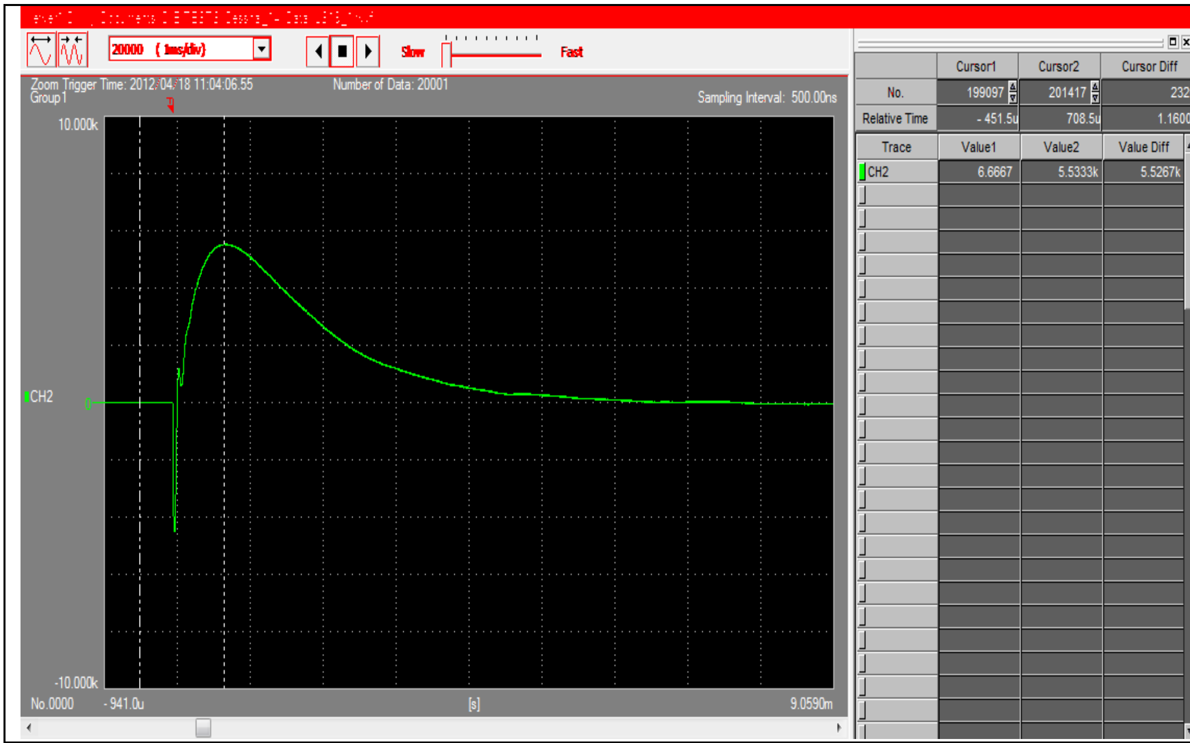


HIGH CURRENT – COMPONENT D	Ip = 95.2 KA	100 uS / Div

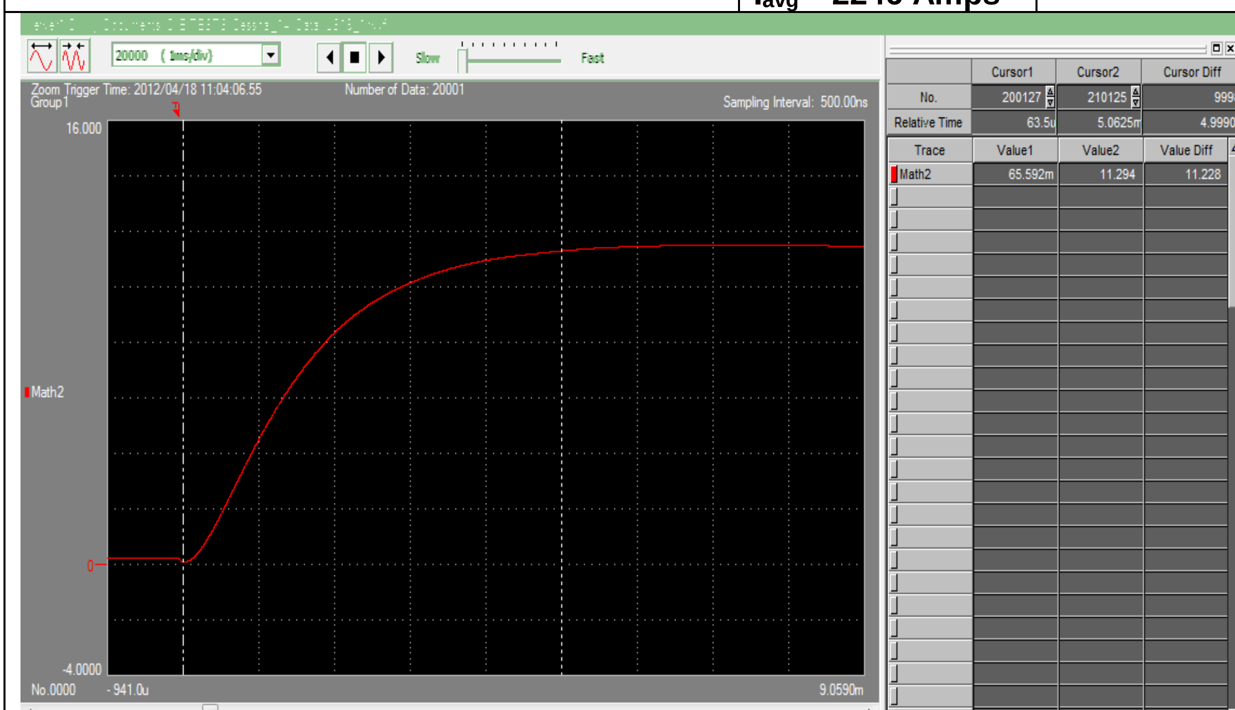


COMPONENT D ACTION INTEGRAL	AI = 270740 A^2-S

PANEL: LS-19

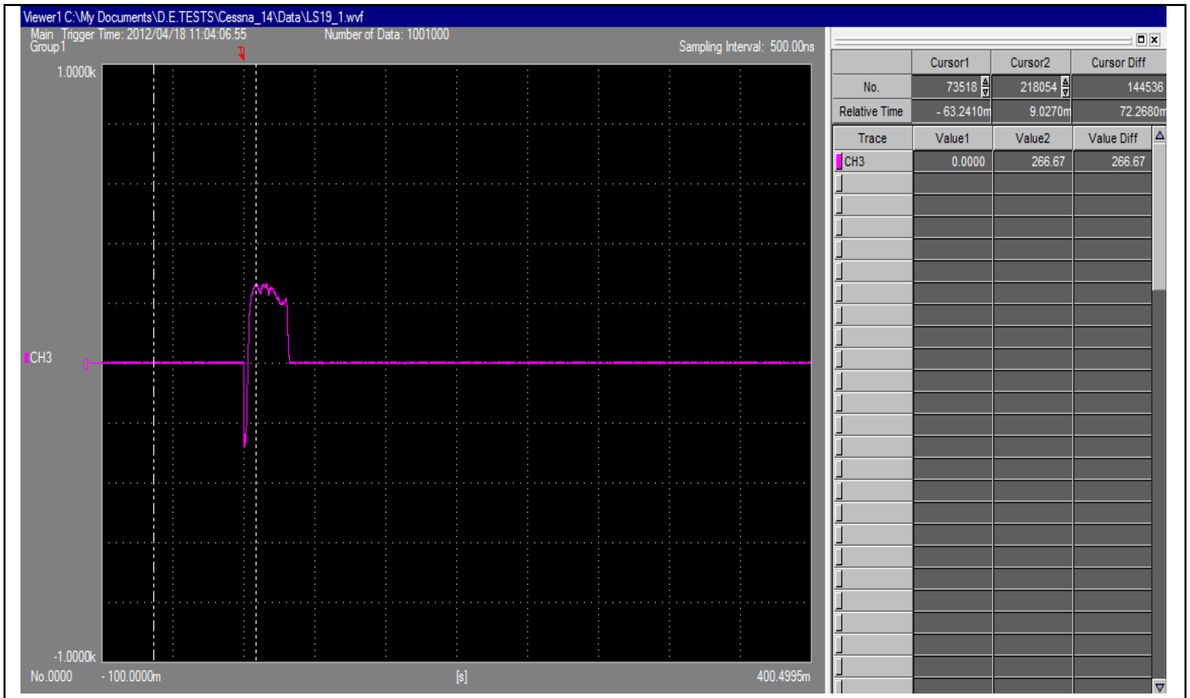


HIGH CURRENT – COMPONENT B | I_P = **5527 Amps** I_{avg} = **2246 Amps** | **1 mS / Div**

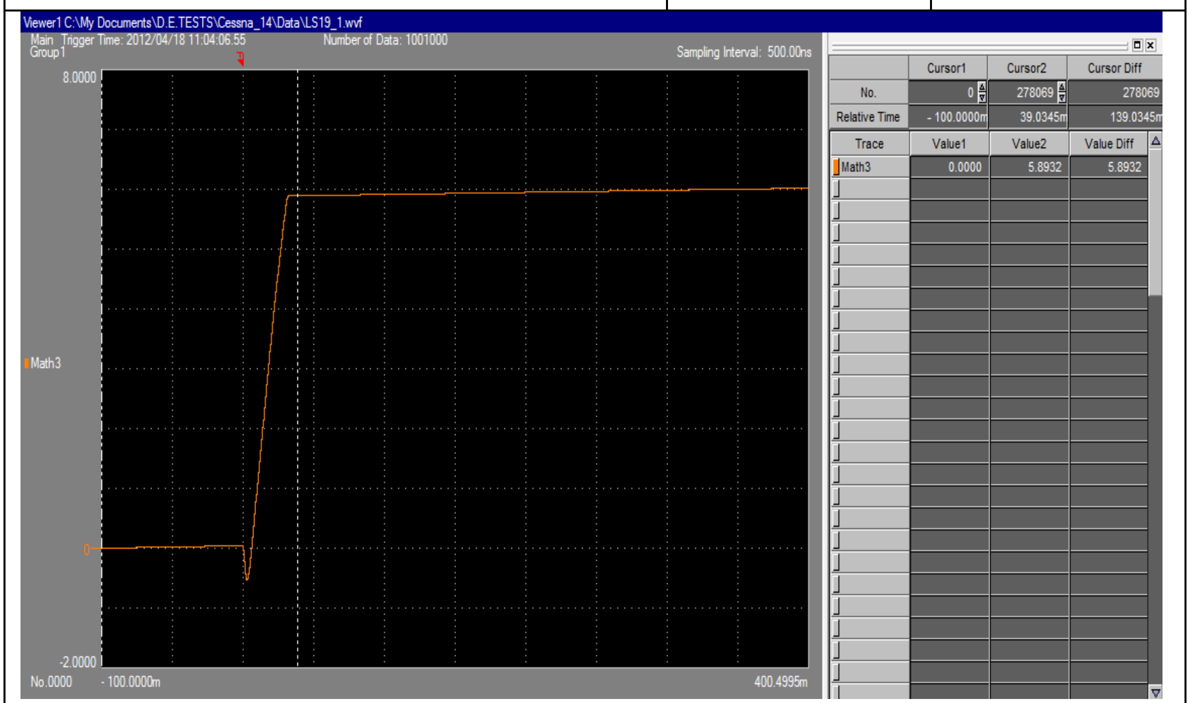


COMPONENT B CHARGE TRANSFER | **11.228 Coulombs**

PANEL: LS-19

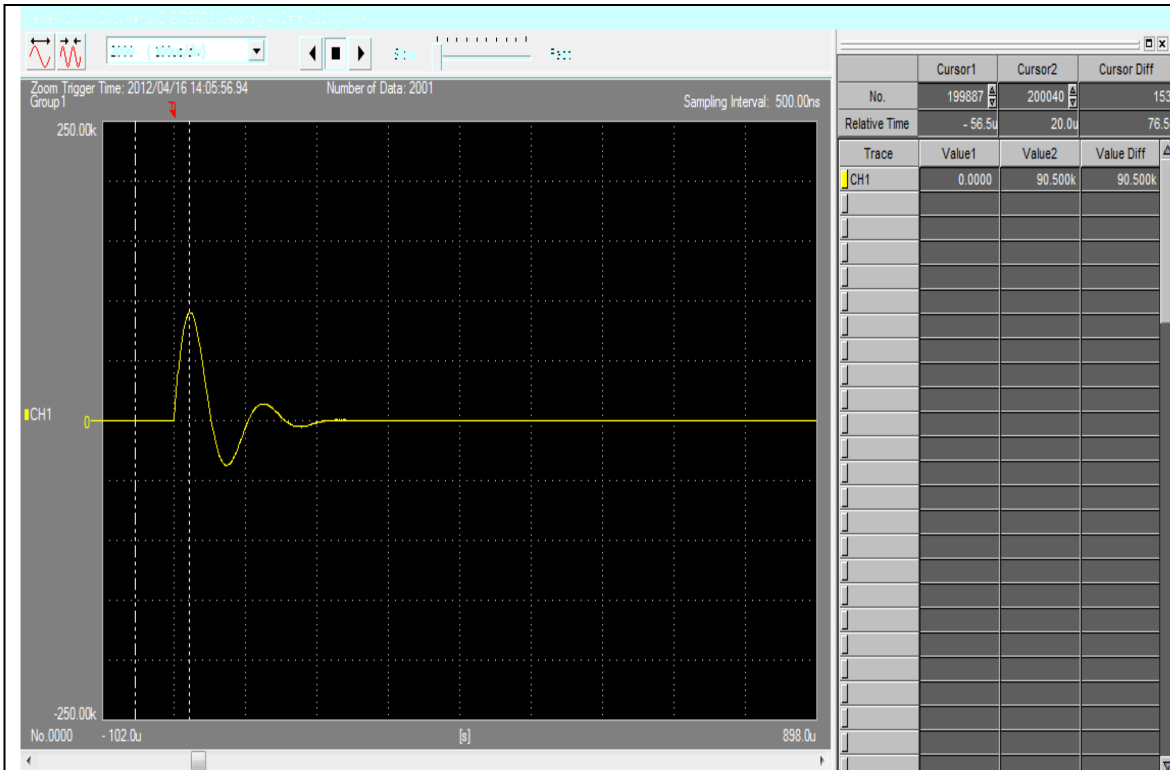


HIGH CURRENT – COMPONENT C*	Ip = 267 Amps	50 mS / Div

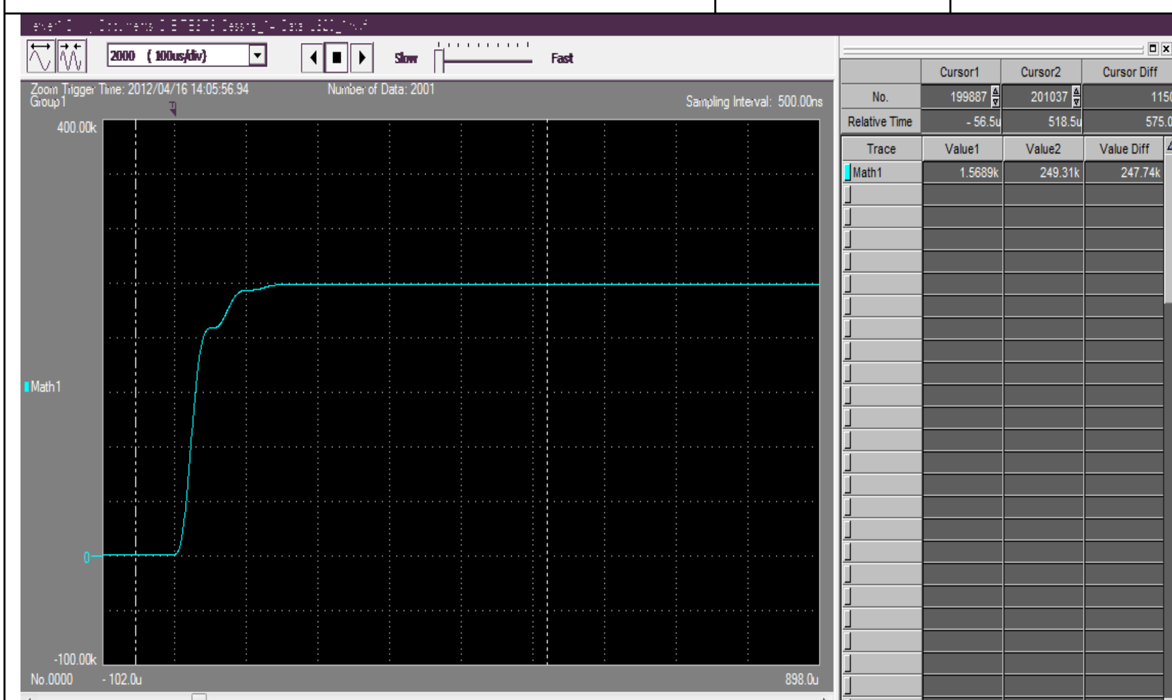


COMPONENT C* CHARGE TRANSFER	5.9 Coulombs

PANEL: LS-19

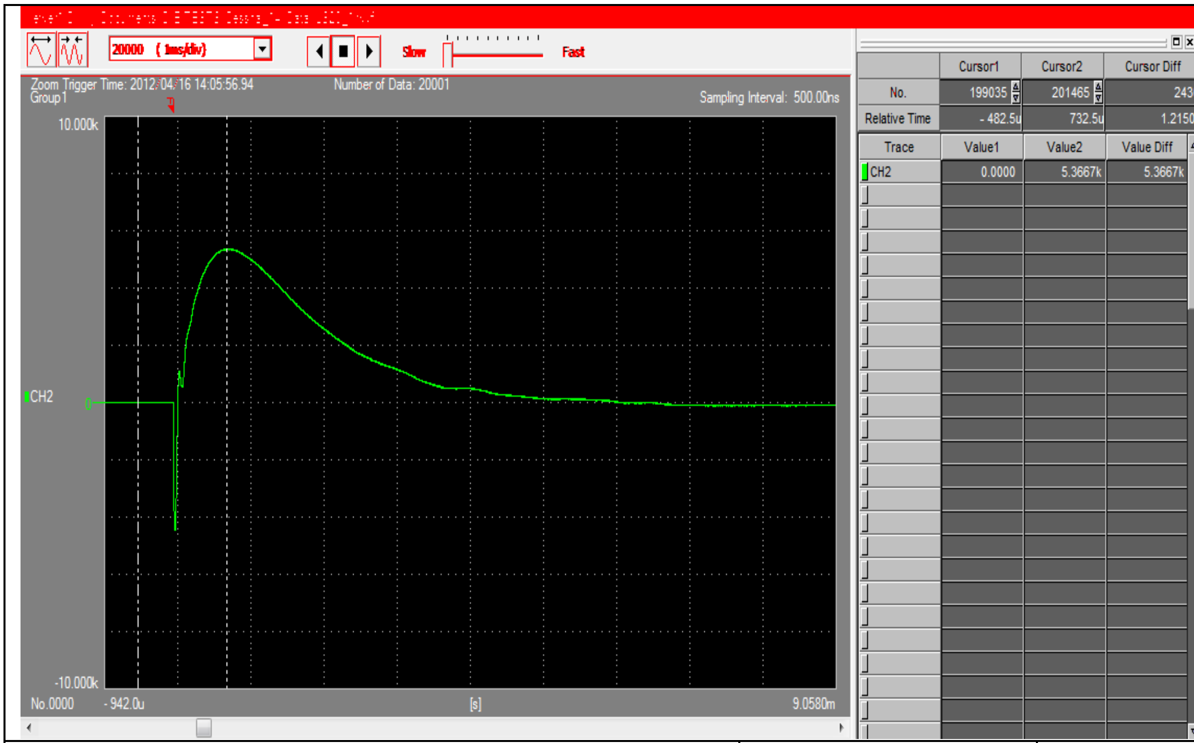


HIGH CURRENT – COMPONENT D	Ip = 90.5 KA	100 uS / Div

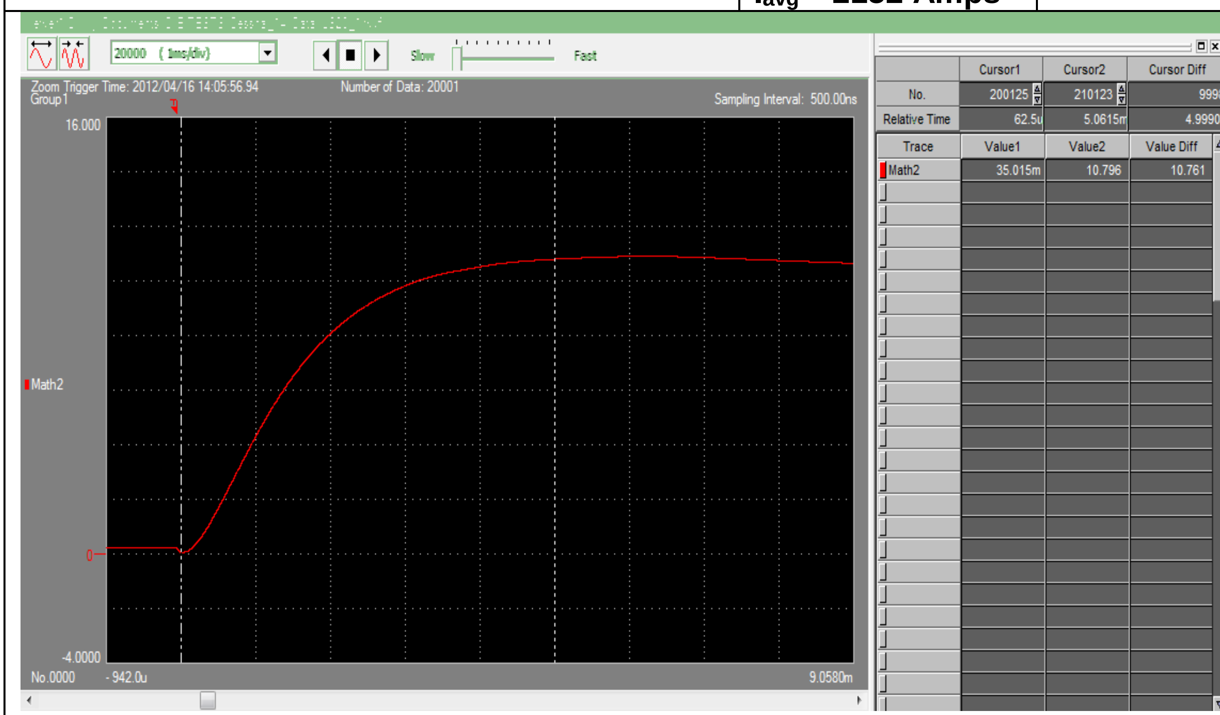


COMPONENT D ACTION INTEGRAL	AI = 247740 A^2-S

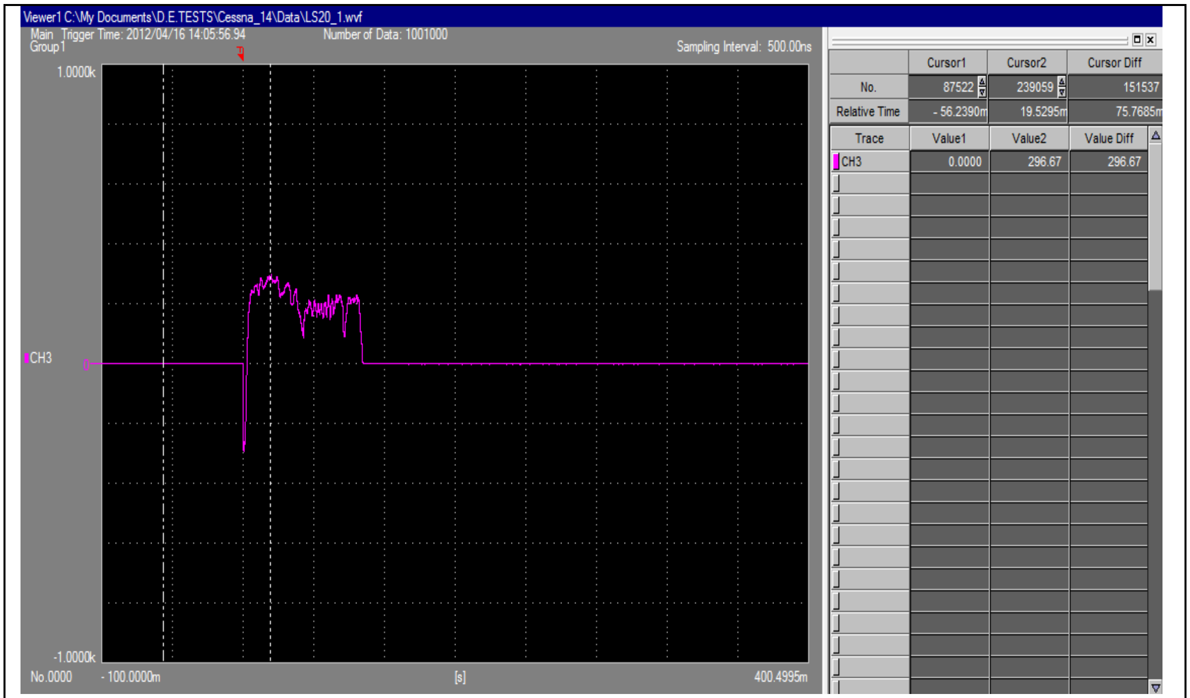
PANEL: LS-20



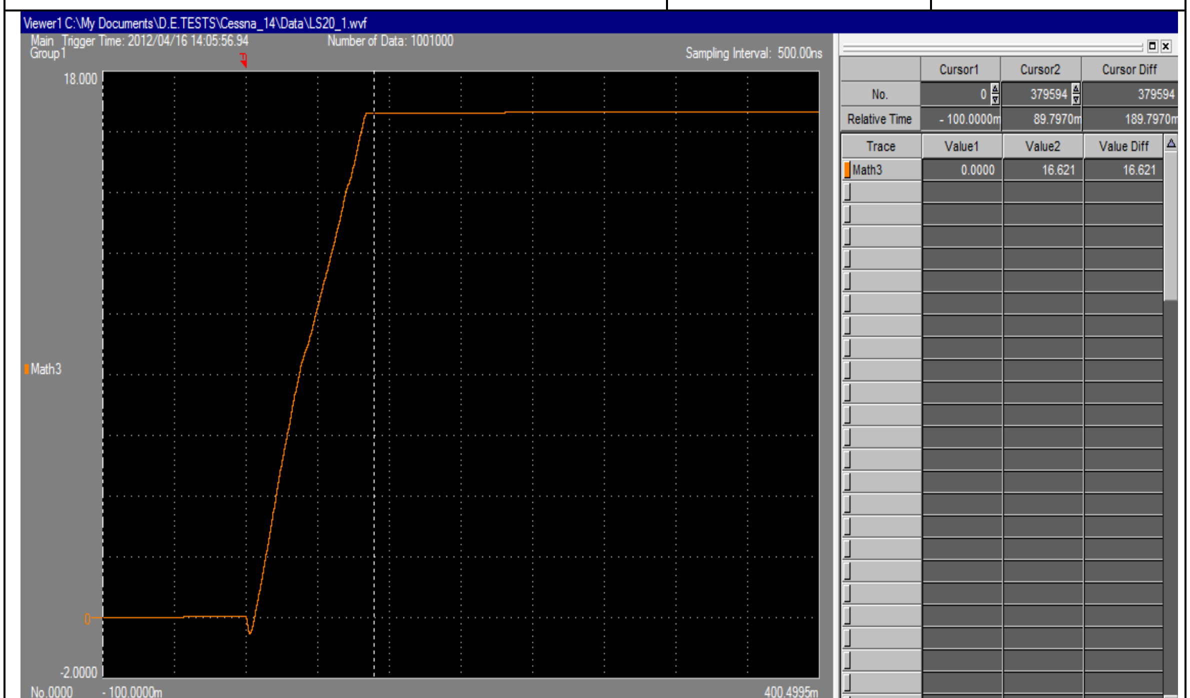
HIGH CURRENT – COMPONENT B	**I_P = 5367 Amps** **I_{avg} = 2152 Amps**	**1 mS / Div**



COMPONENT B CHARGE TRANSFER	**10.761 Coulombs**
PANEL: LS-20	

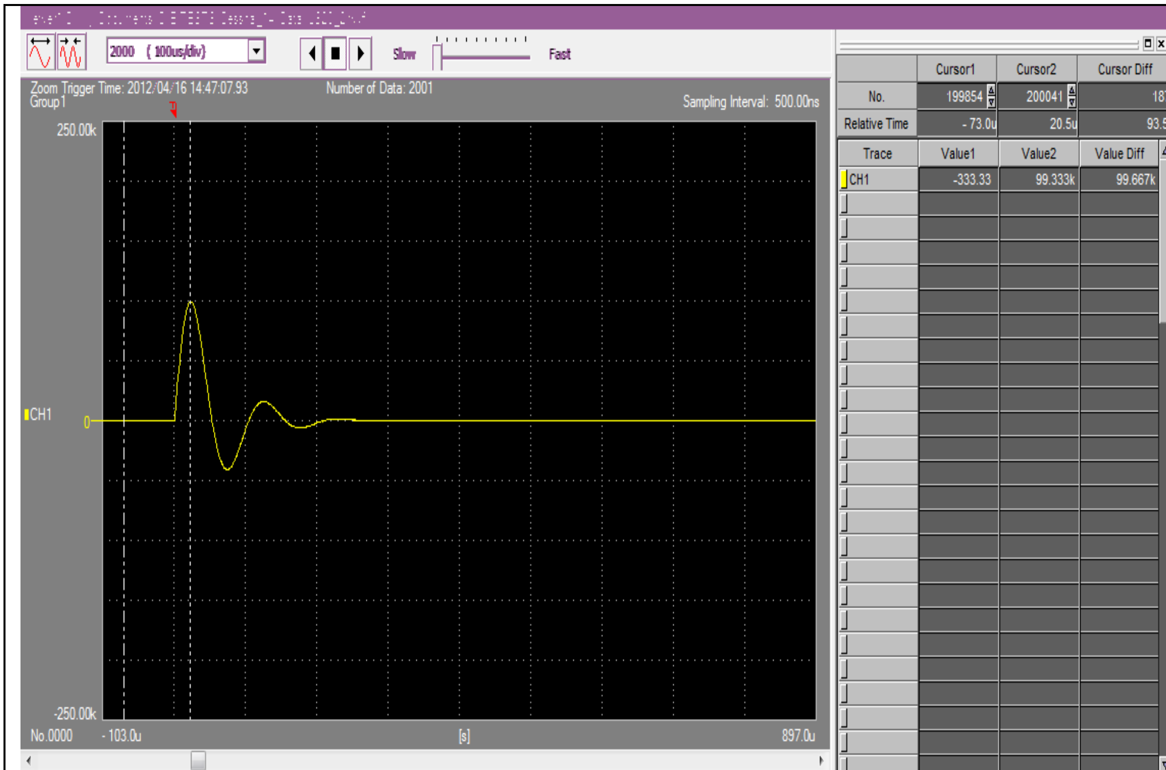


HIGH CURRENT – COMPONENT C*	Ip = 297 Amps	50 mS / Div

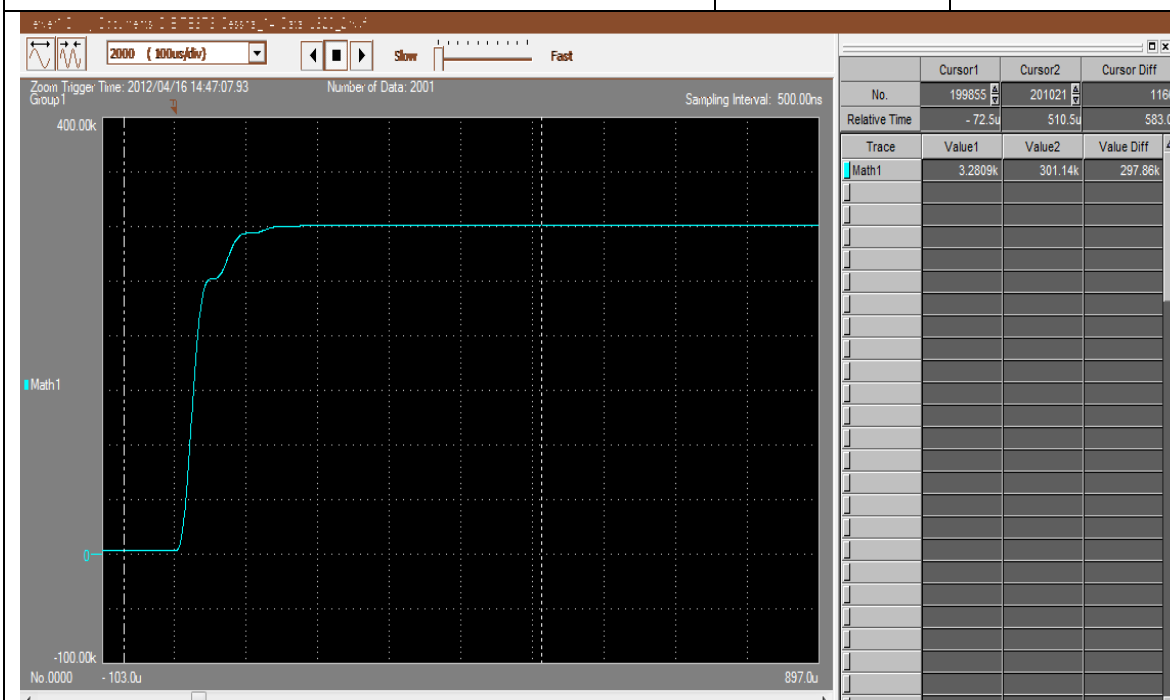


COMPONENT C* CHARGE TRANSFER	16.6 Coulombs

PANEL: LS-20

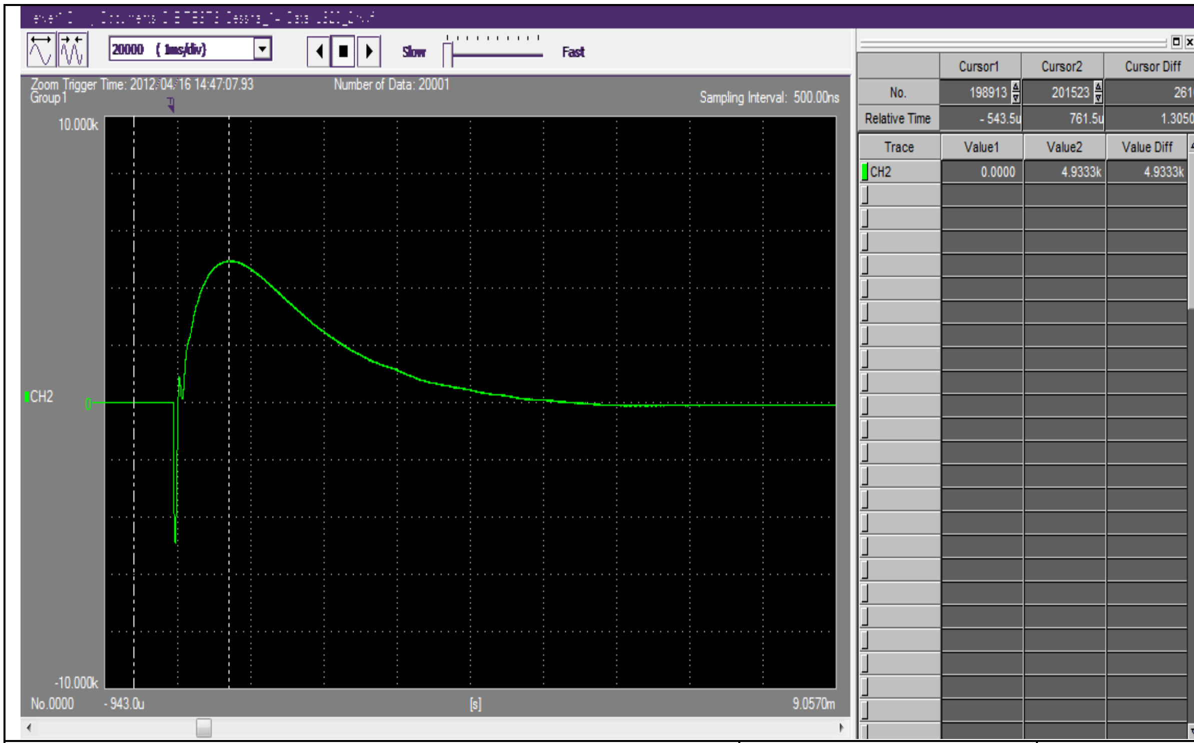


HIGH CURRENT – COMPONENT D	Ip = 99.7 KA	100 uS / Div

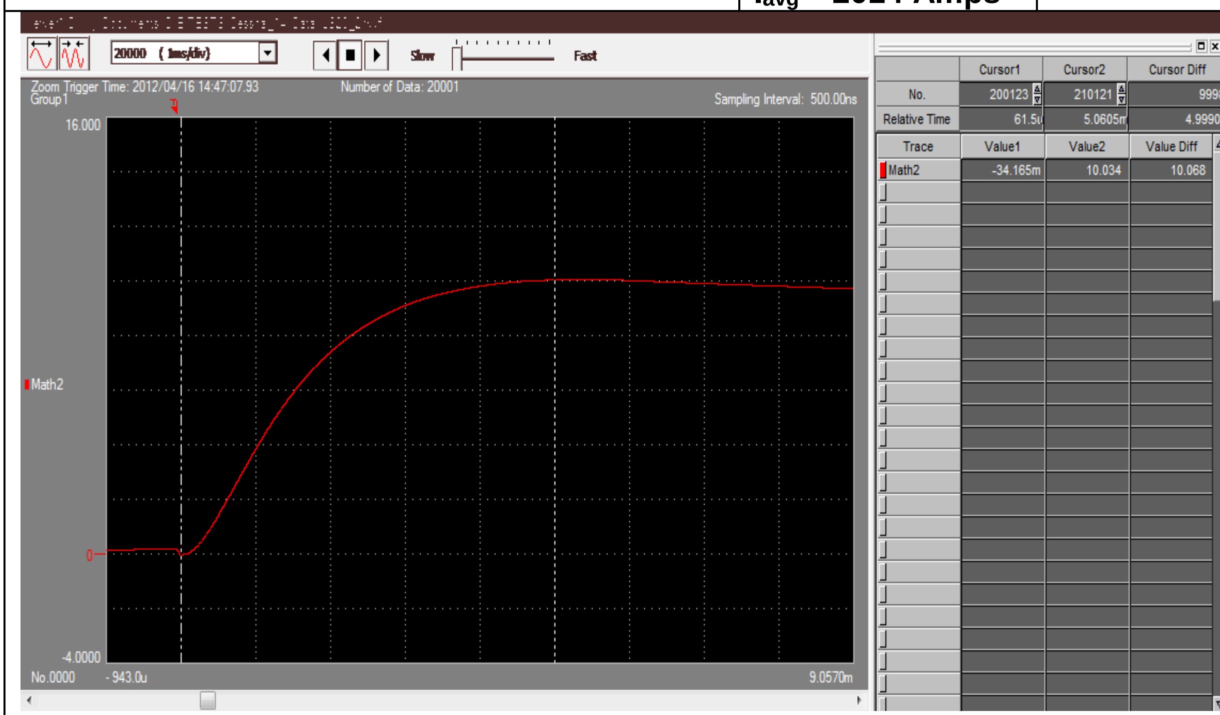


COMPONENT D ACTION INTEGRAL	AI = 297860 A^2-S

PANEL: LS-20 Second Strike

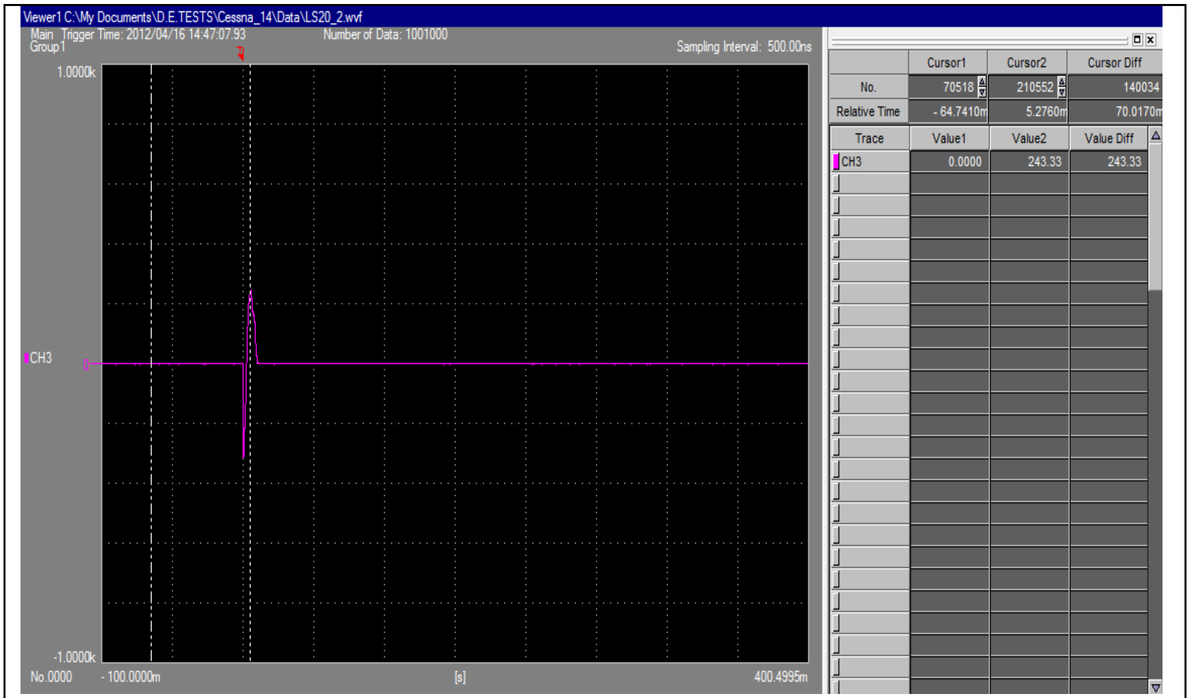


HIGH CURRENT – COMPONENT B	I_P = 4933 Amps I_{avg} = 2014 Amps	1 mS / Div

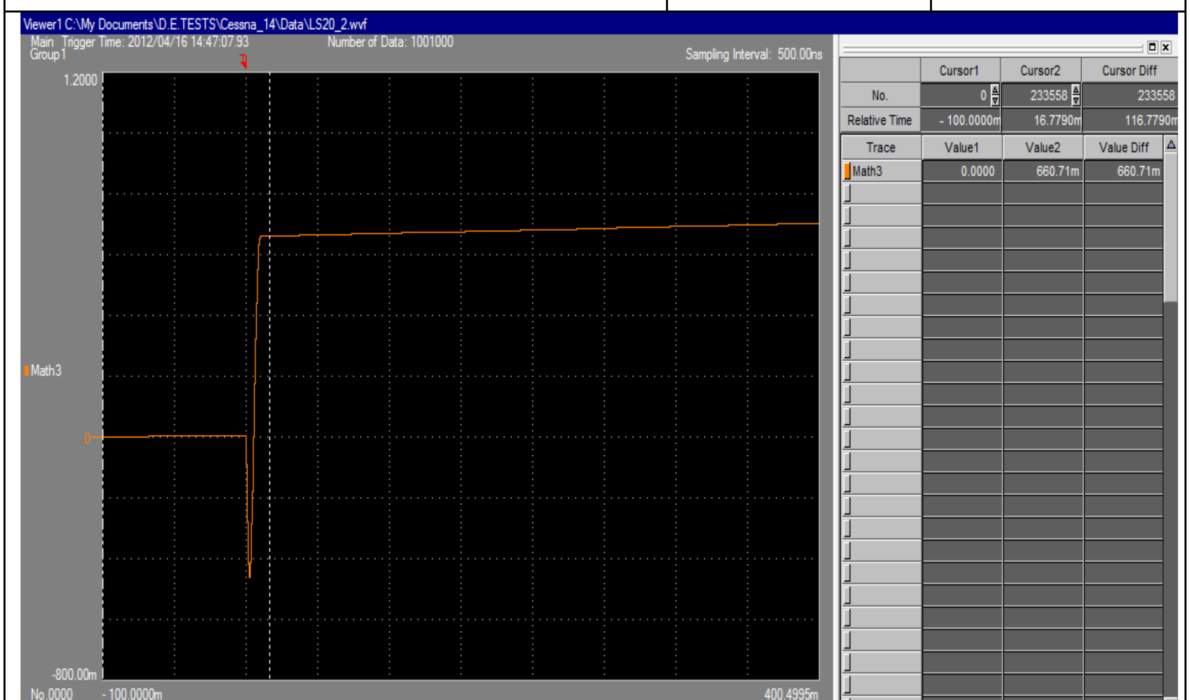


COMPONENT B CHARGE TRANSFER	10.068 Coulombs

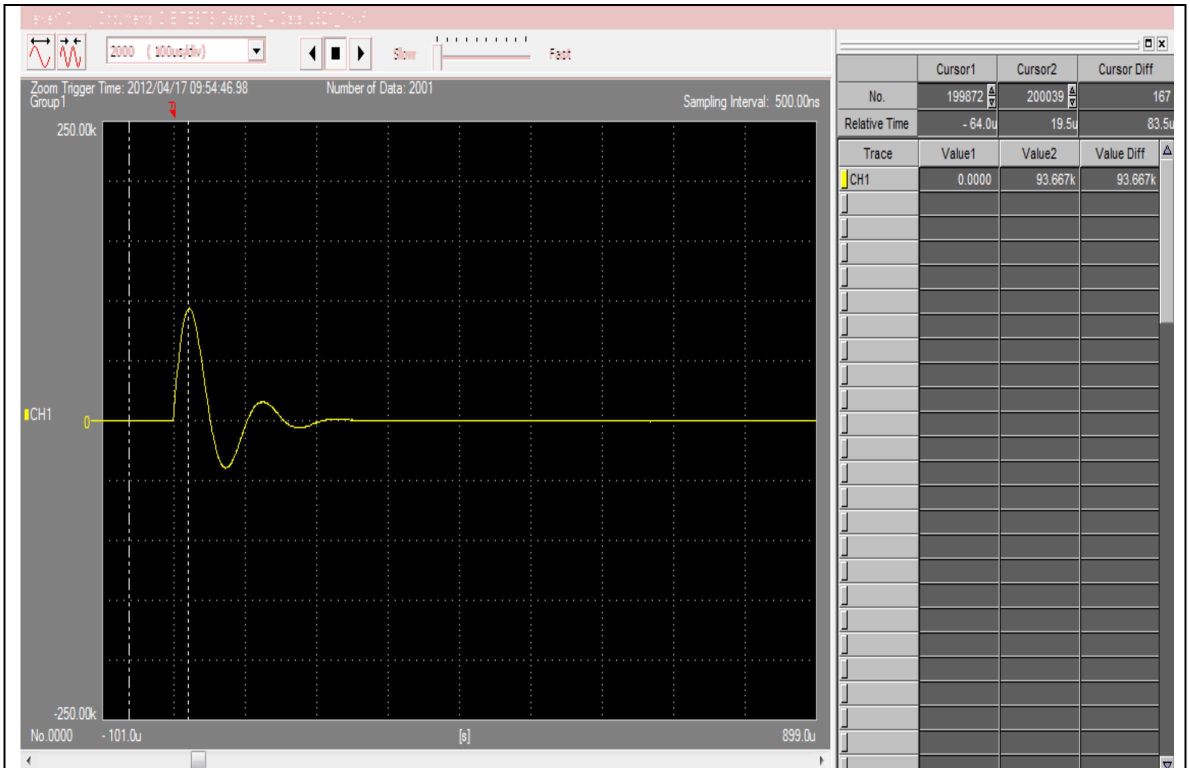
PANEL: LS-20 Second Strike



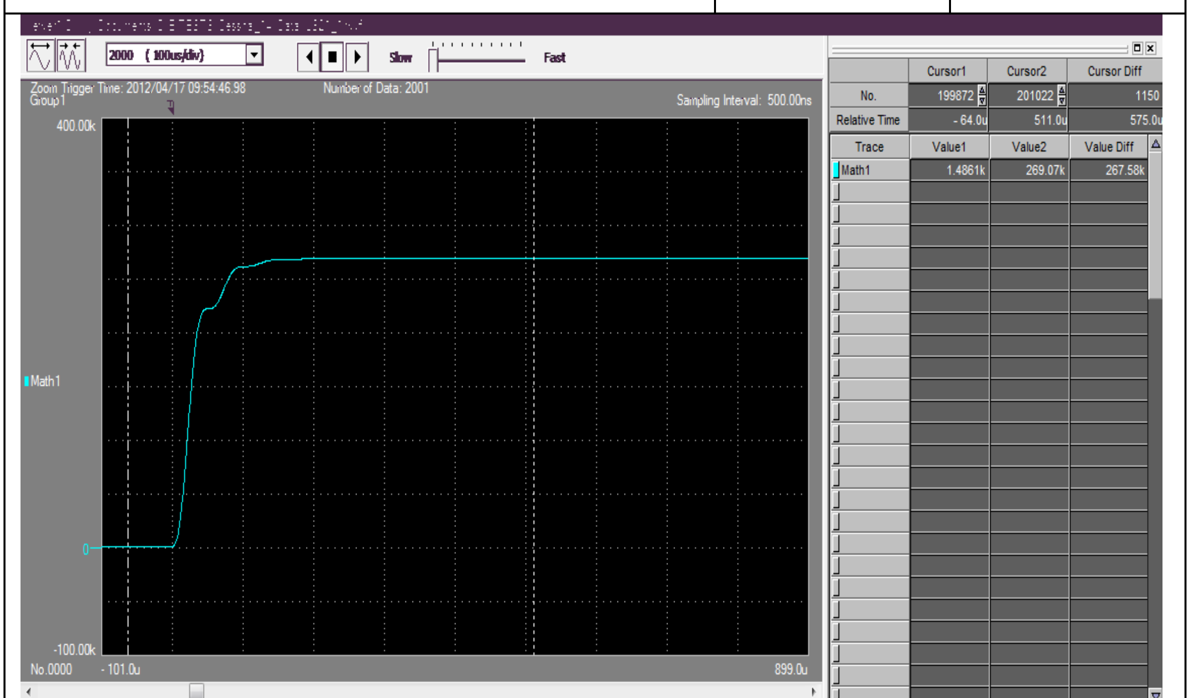
HIGH CURRENT – COMPONENT C*	Ip = 243 Amps	50 mS / Div



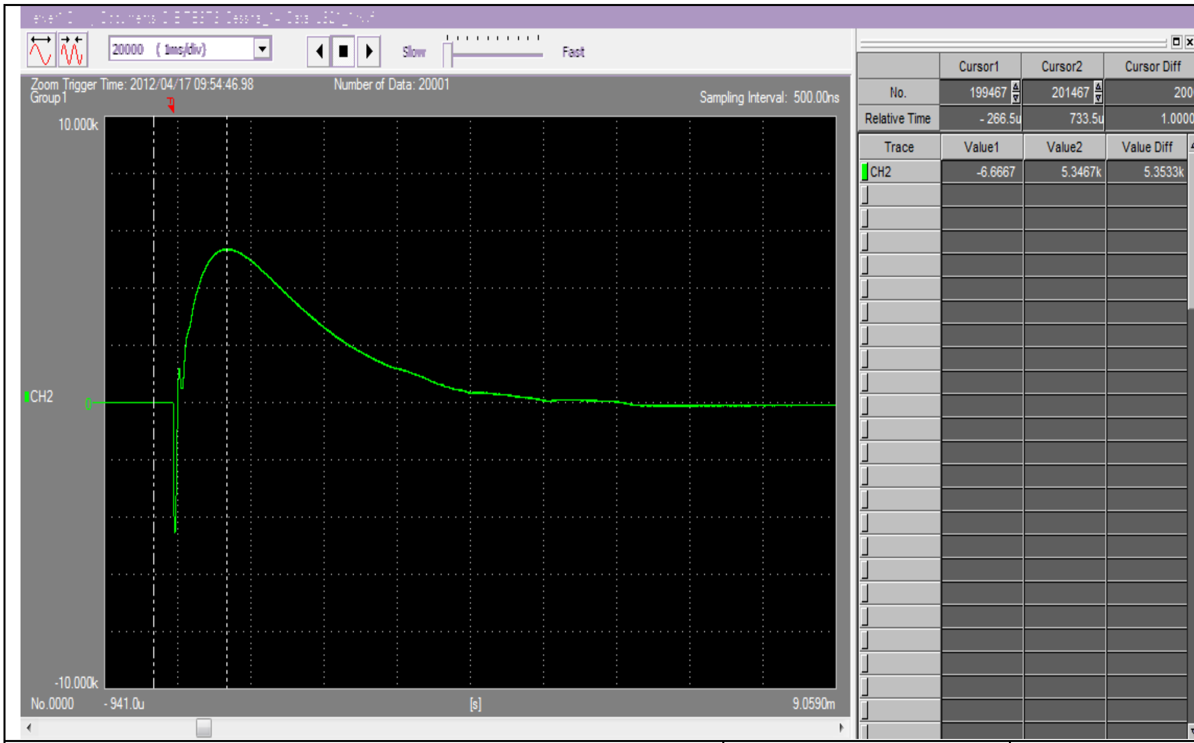
COMPONENT C* CHARGE TRANSFER	0.66 Coulombs
PANEL: LS-20 Second Strike	



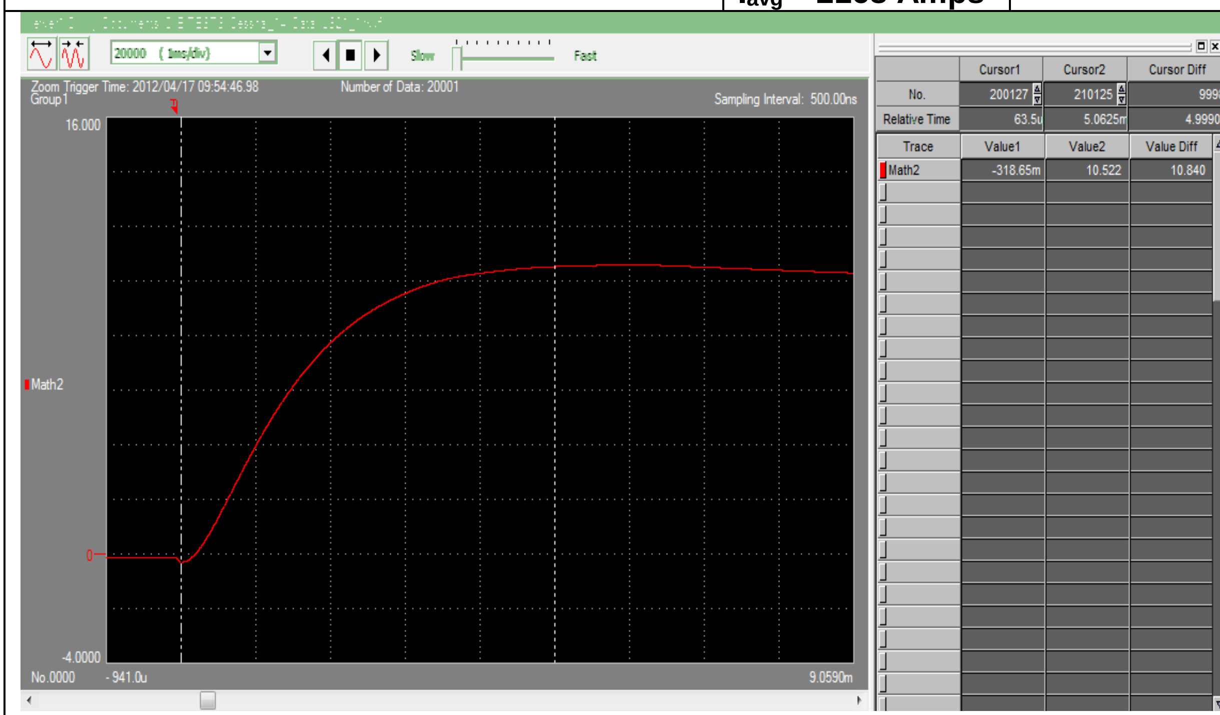
HIGH CURRENT – COMPONENT D	Ip = 93.7 KA	100 uS / Div



COMPONENT D ACTION INTEGRAL	AI = 267580 A^2-S
PANEL: LS-21	

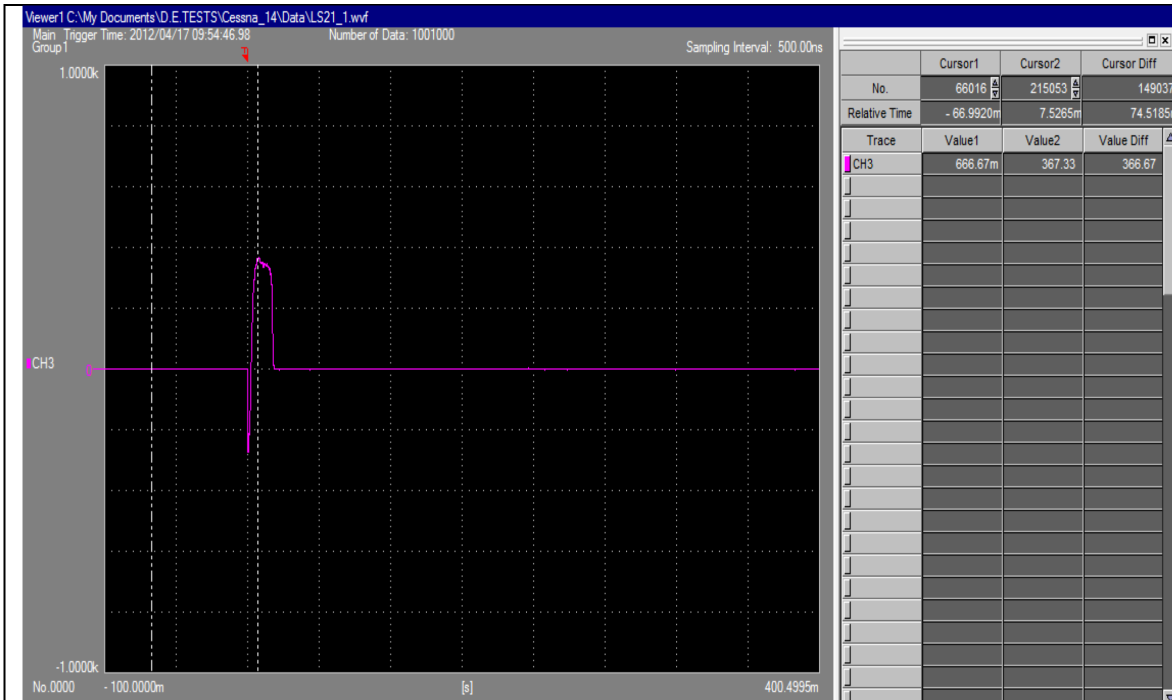


HIGH CURRENT – COMPONENT B	I_P = 5353 Amps I_{avg} = 2168 Amps	1 mS / Div

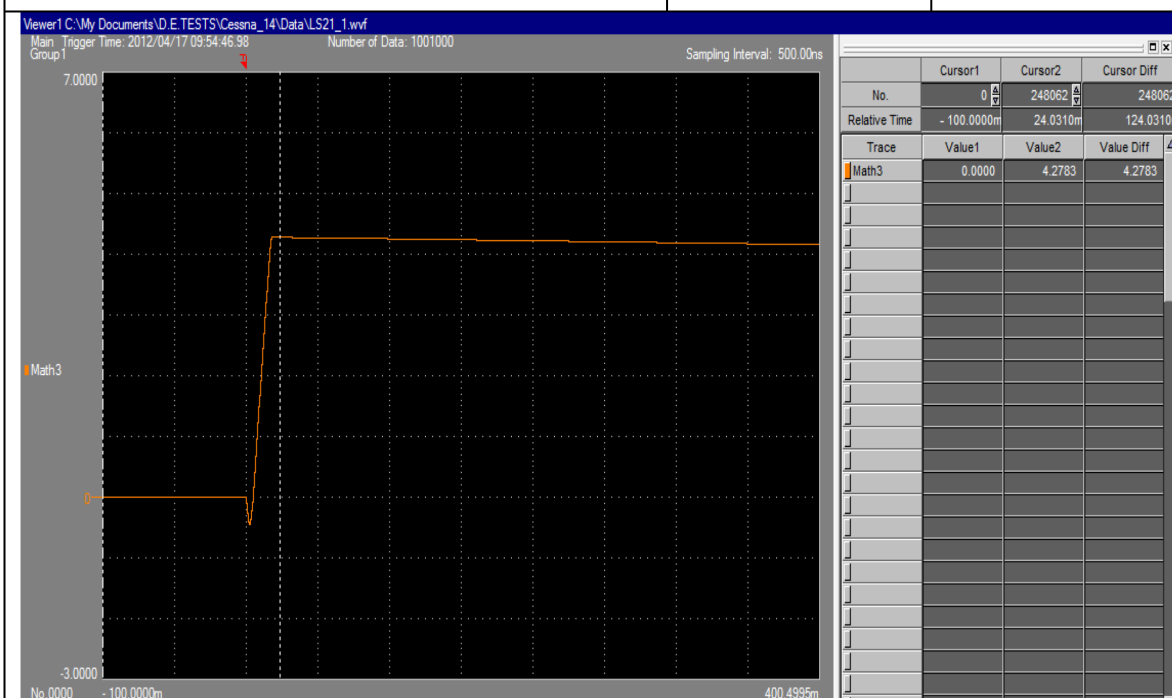


COMPONENT B CHARGE TRANSFER	10.840 Coulombs

PANEL: LS-21

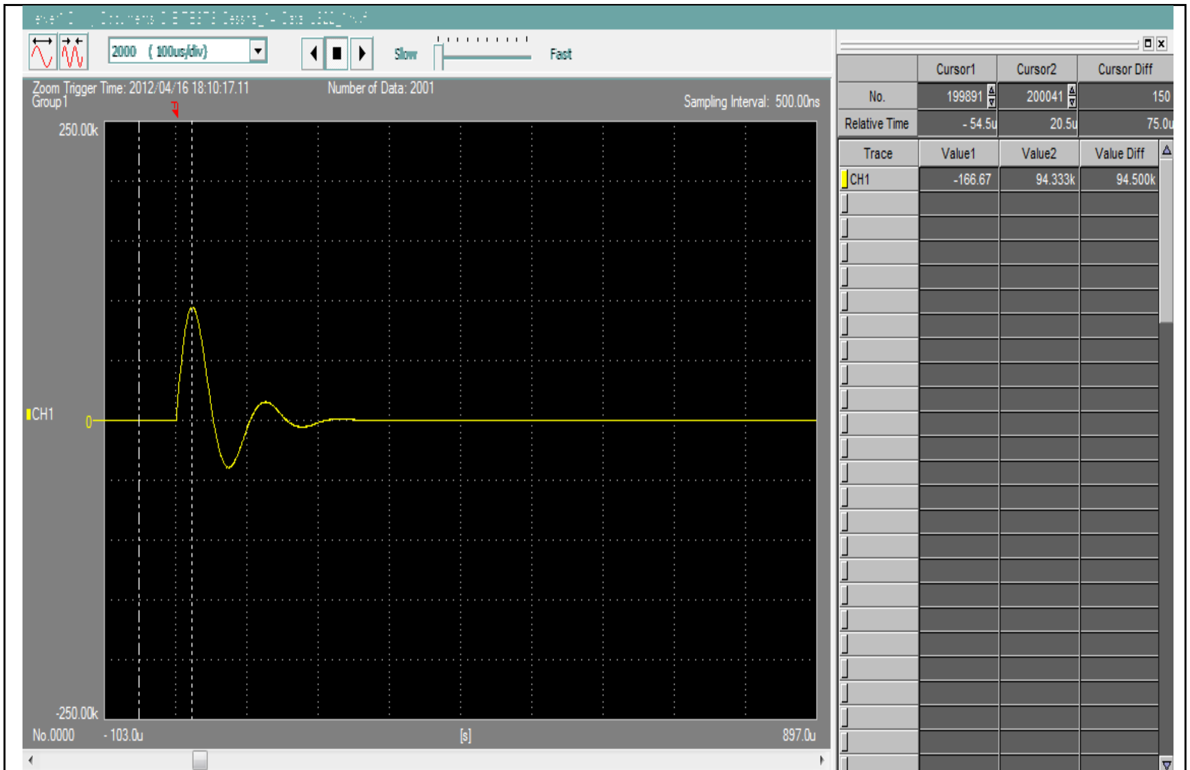


HIGH CURRENT – COMPONENT C* | **Ip = 367 Amps** | **50 mS / Div**

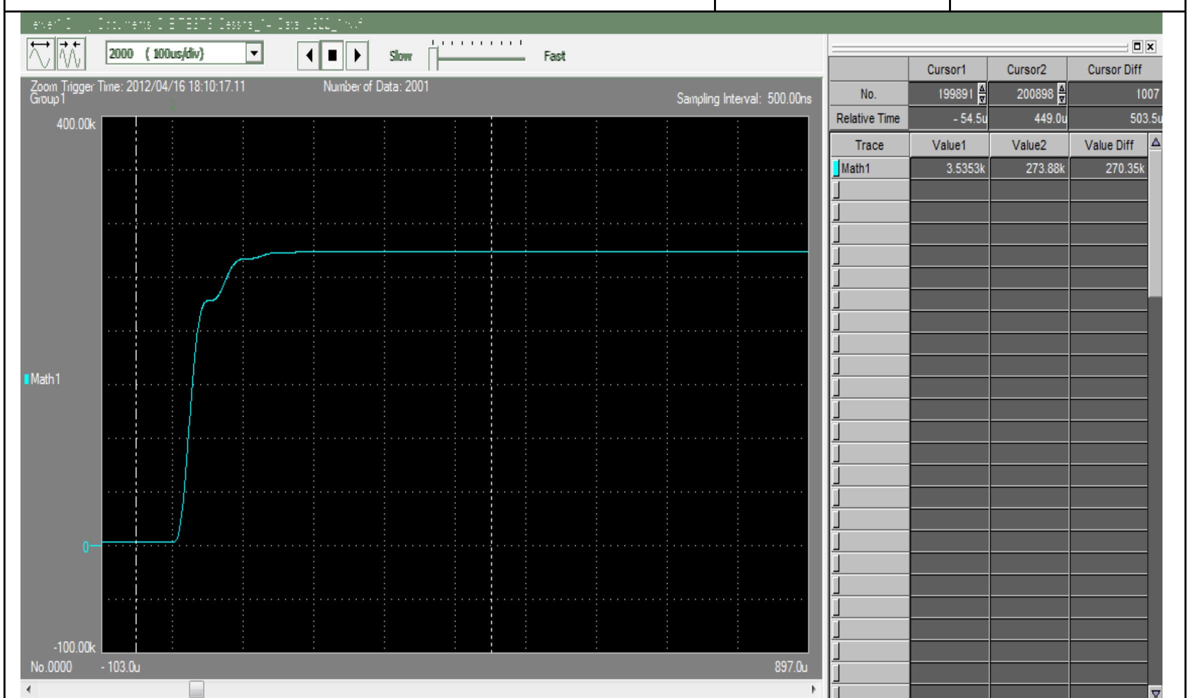


COMPONENT C* CHARGE TRANSFER | **4.3 Coulombs**

PANEL: LS-21

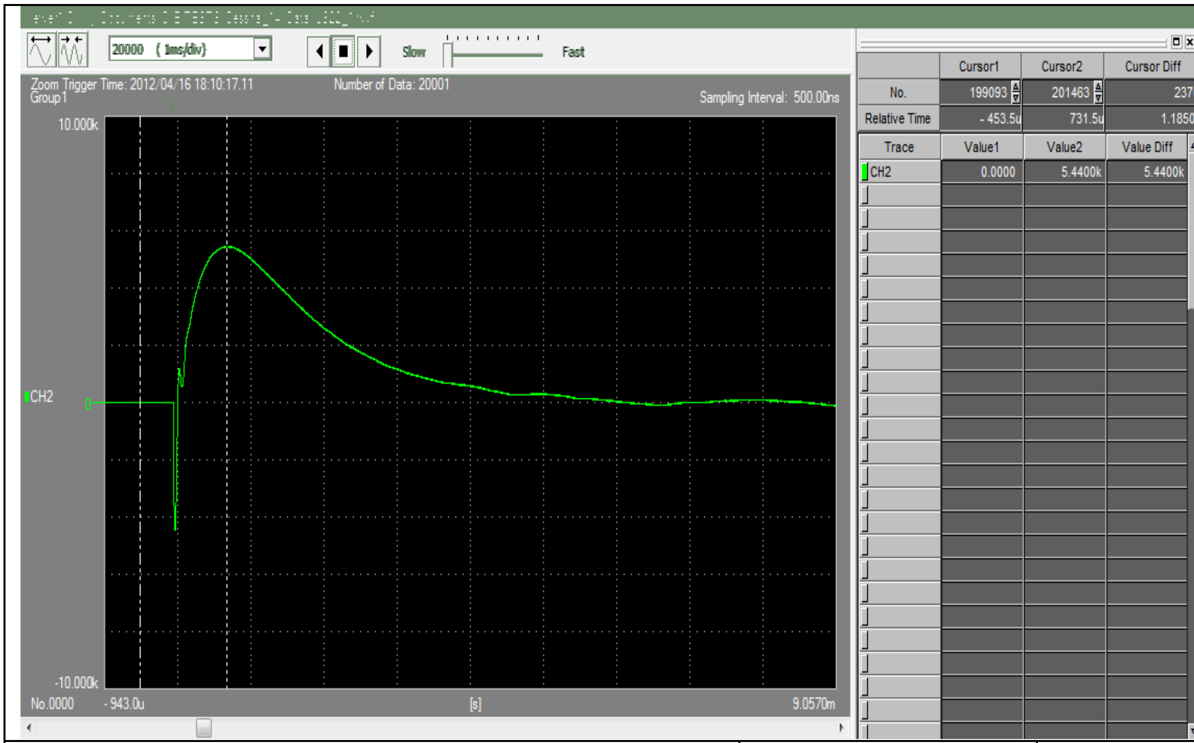


HIGH CURRENT – COMPONENT D	Ip = 94.5 KA	100 uS / Div

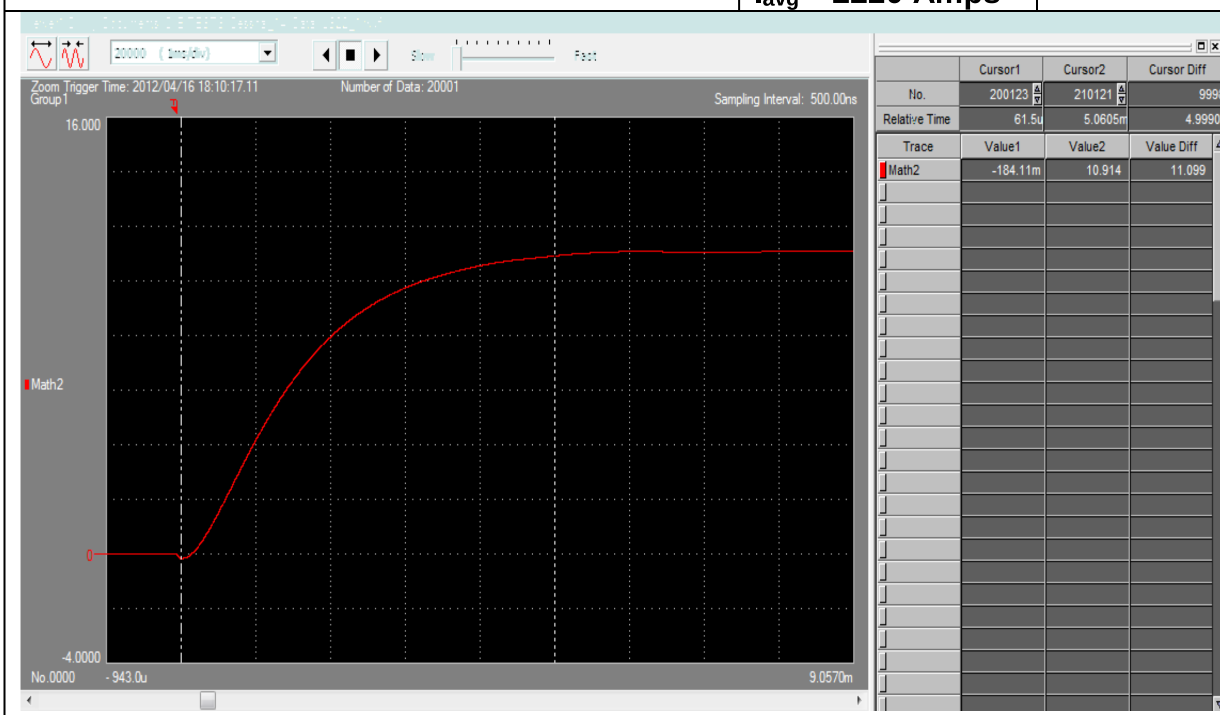


COMPONENT D ACTION INTEGRAL	AI = 270350 A^2-S

PANEL: LS-22

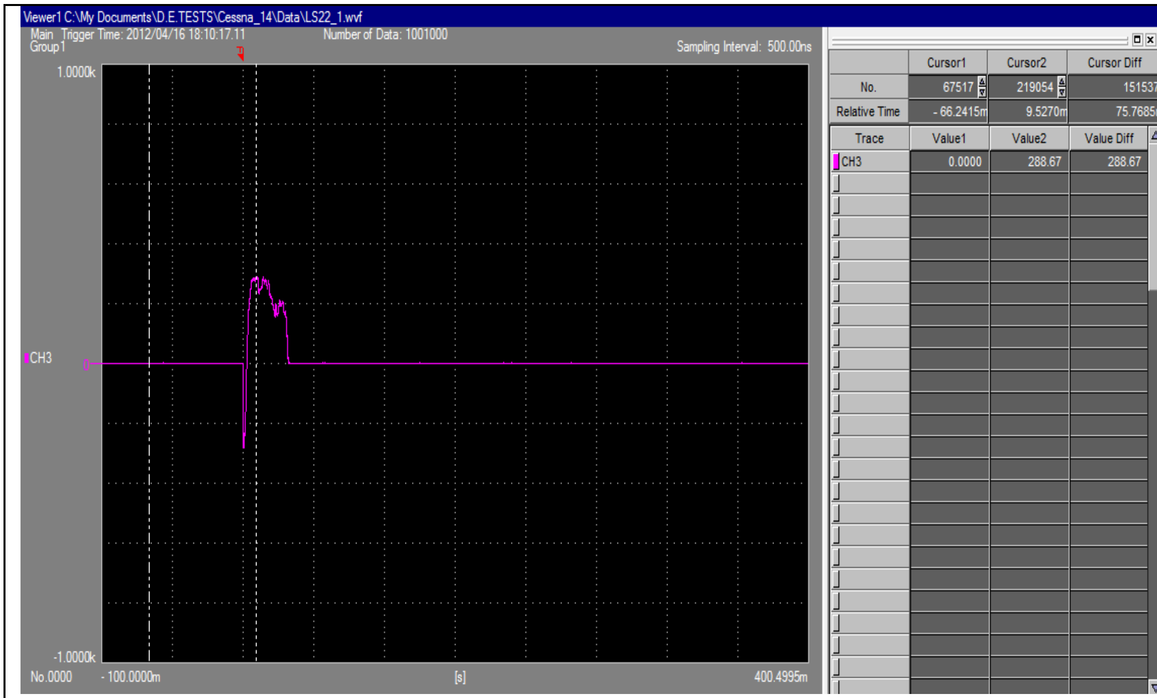


HIGH CURRENT – COMPONENT B	I_P = 5440 Amps I_{avg} = 2220 Amps	1 mS / Div

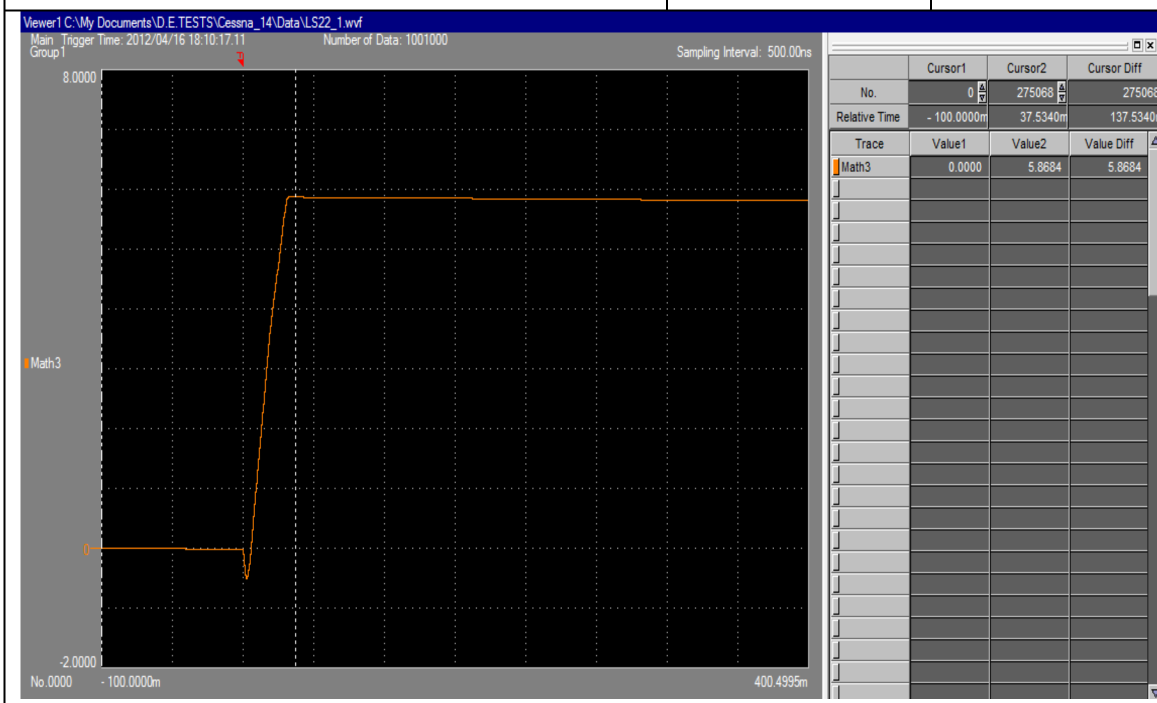


COMPONENT B CHARGE TRANSFER	11.099 Coulombs

PANEL: LS-22

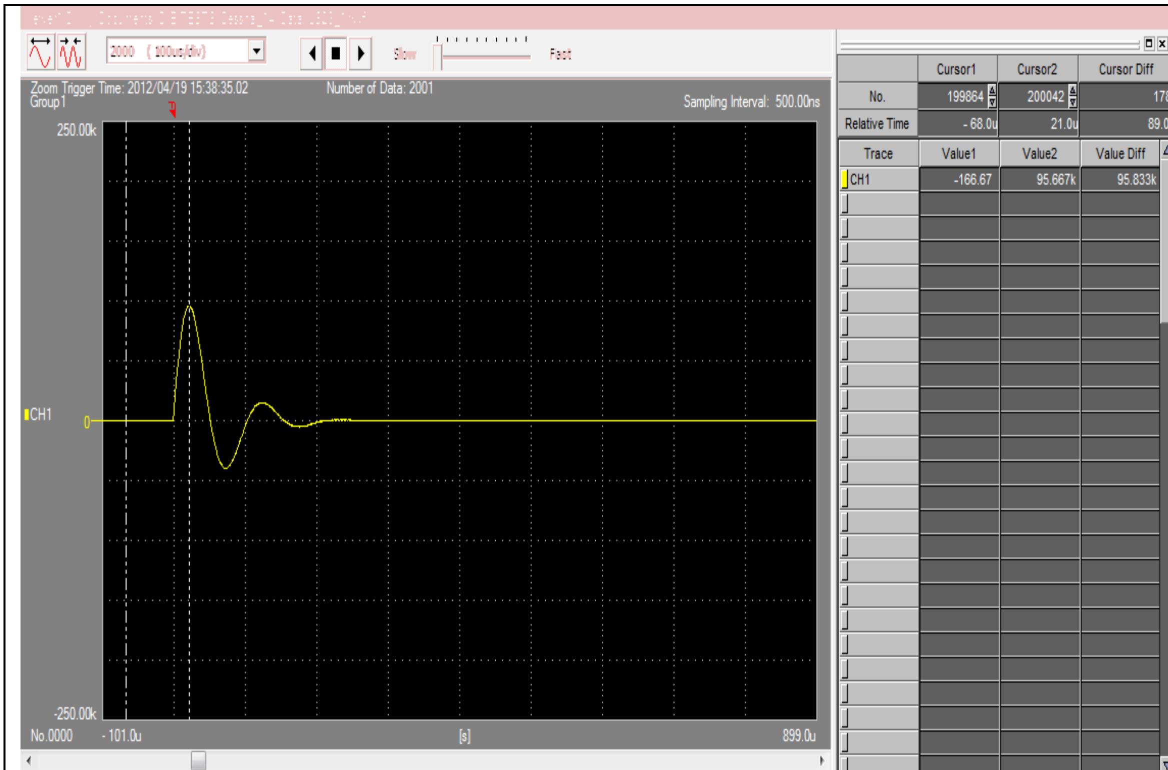


HIGH CURRENT – COMPONENT C*	Ip = 289 Amps	50 mS / Div

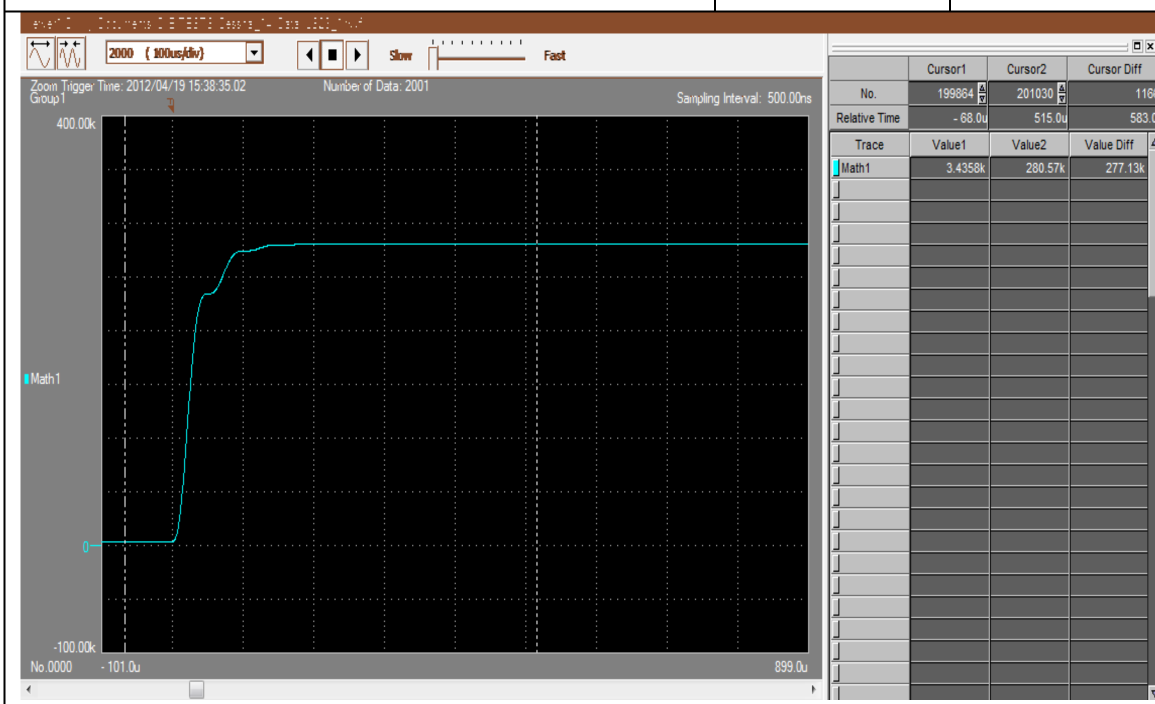


COMPONENT C* CHARGE TRANSFER	5.9 Coulombs

PANEL: LS-22

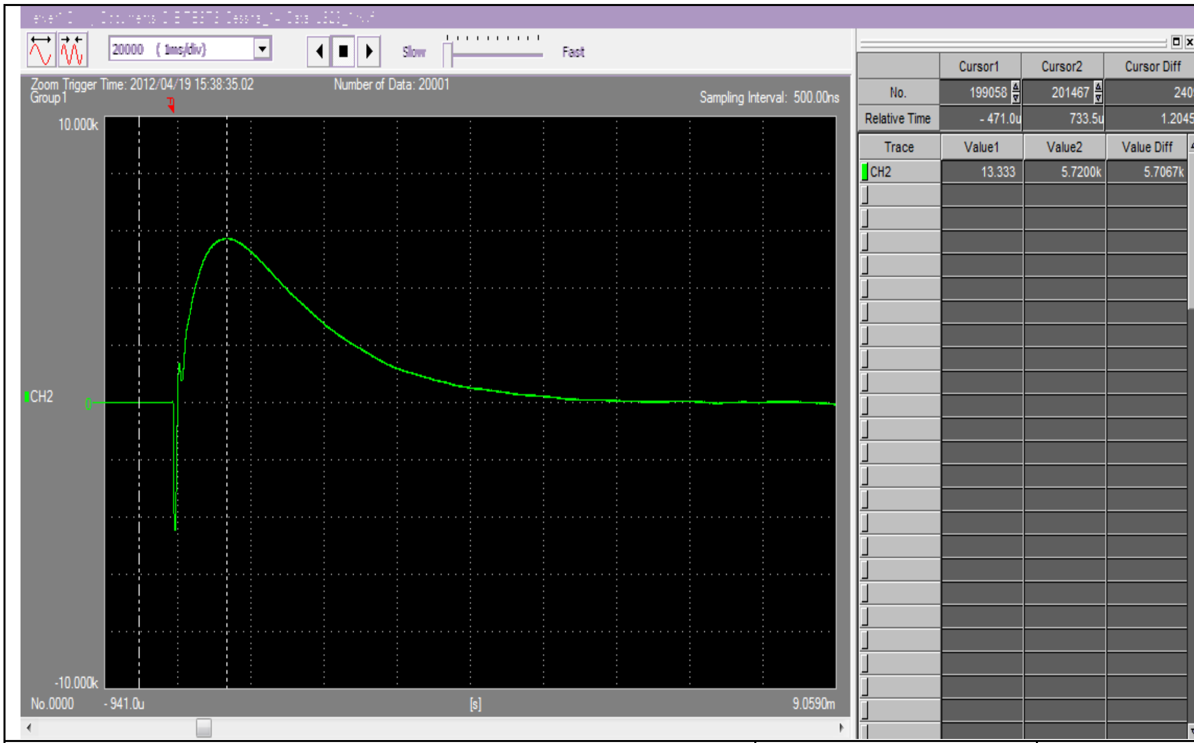


HIGH CURRENT – COMPONENT D	Ip = 95.8 KA	100 uS / Div

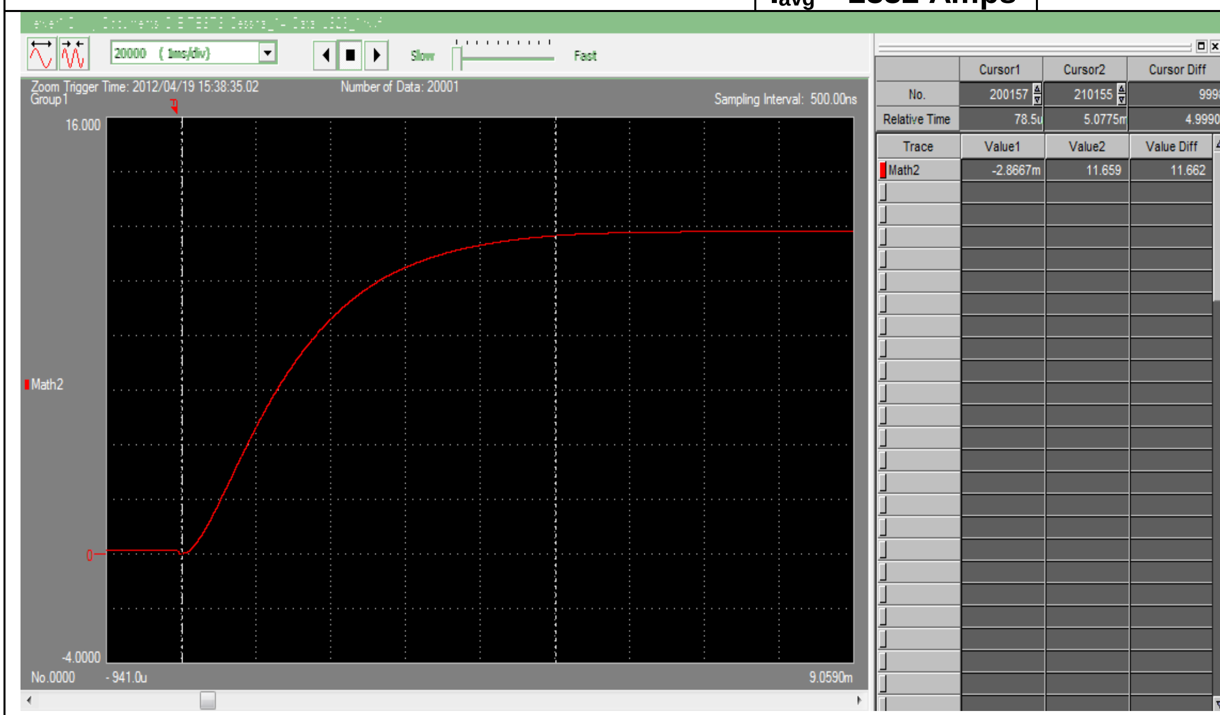


COMPONENT D ACTION INTEGRAL	AI = 277130 A^2-S

PANEL: LS-23

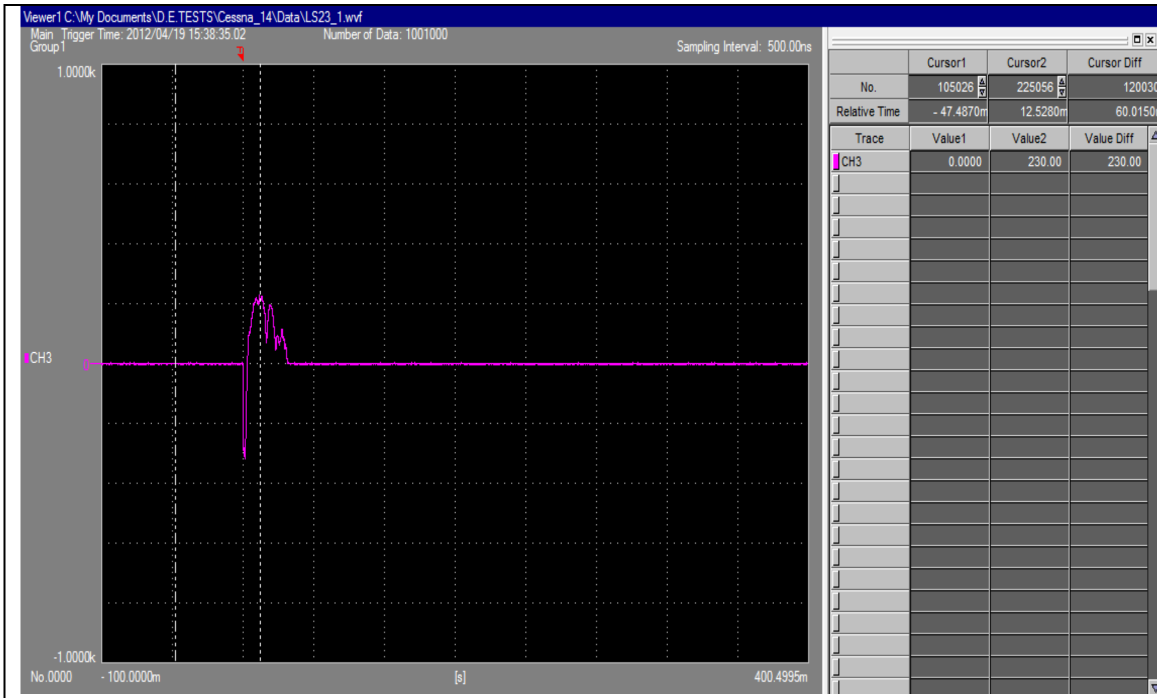


HIGH CURRENT – COMPONENT B	**I_P = 5707 Amps** **I_{avg} = 2332 Amps**	**1 mS / Div**

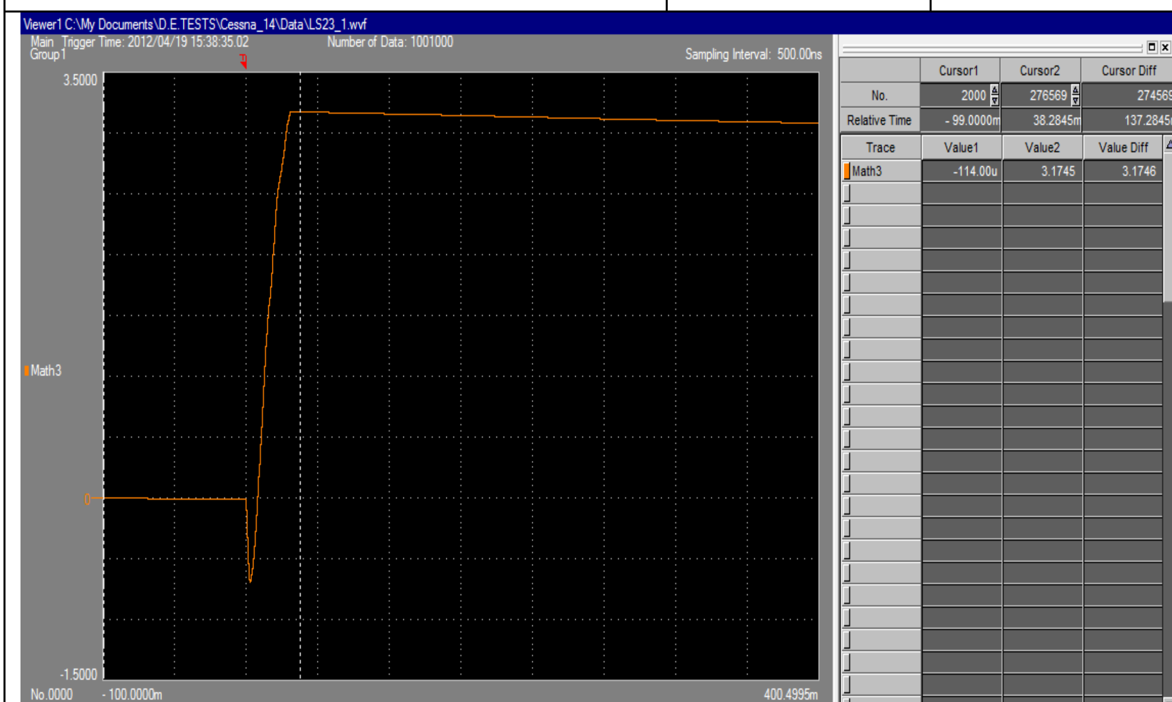


COMPONENT B CHARGE TRANSFER	**11.662 Coulombs**

PANEL: LS-23

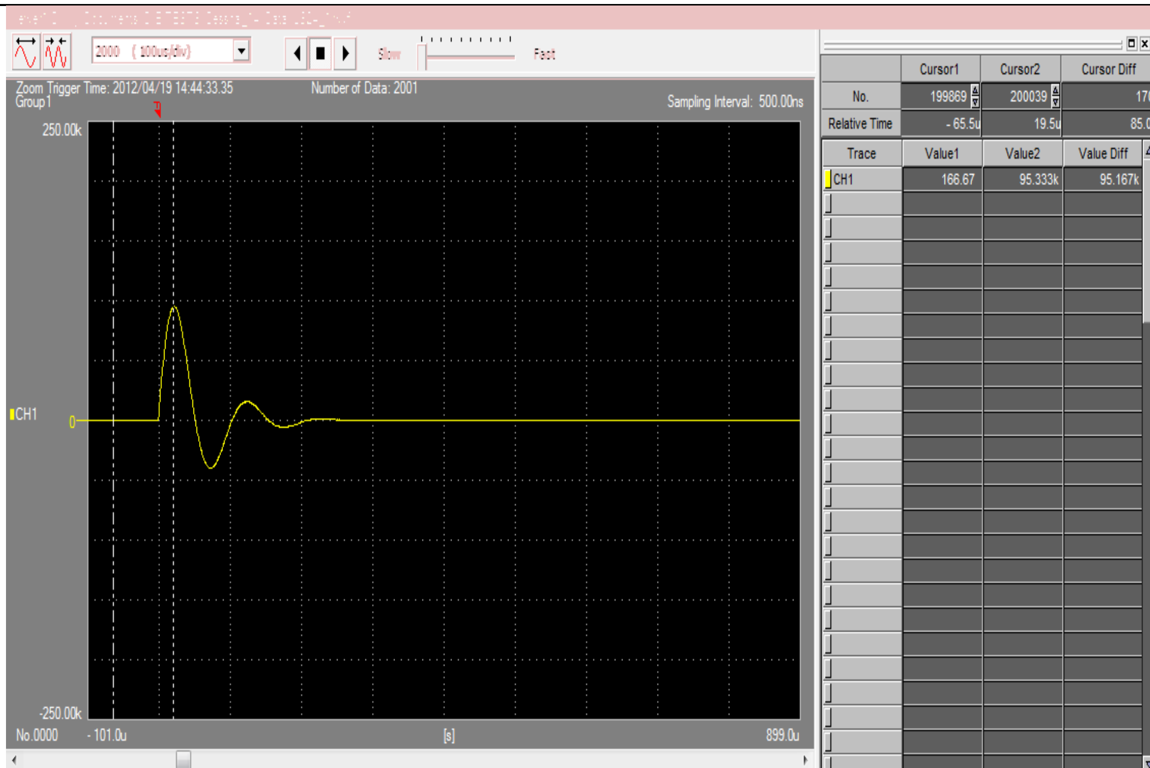


HIGH CURRENT – COMPONENT C*	Ip = 230 Amps	50 mS / Div

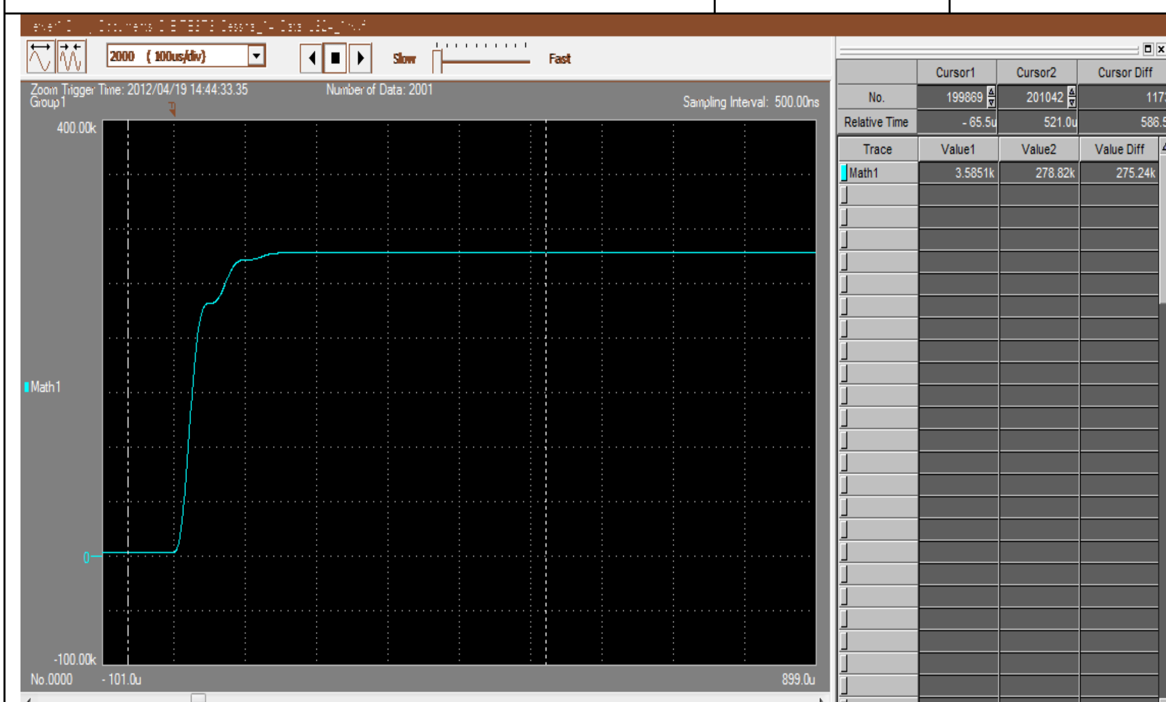


COMPONENT C* CHARGE TRANSFER	3.2 Coulombs

PANEL: LS-23

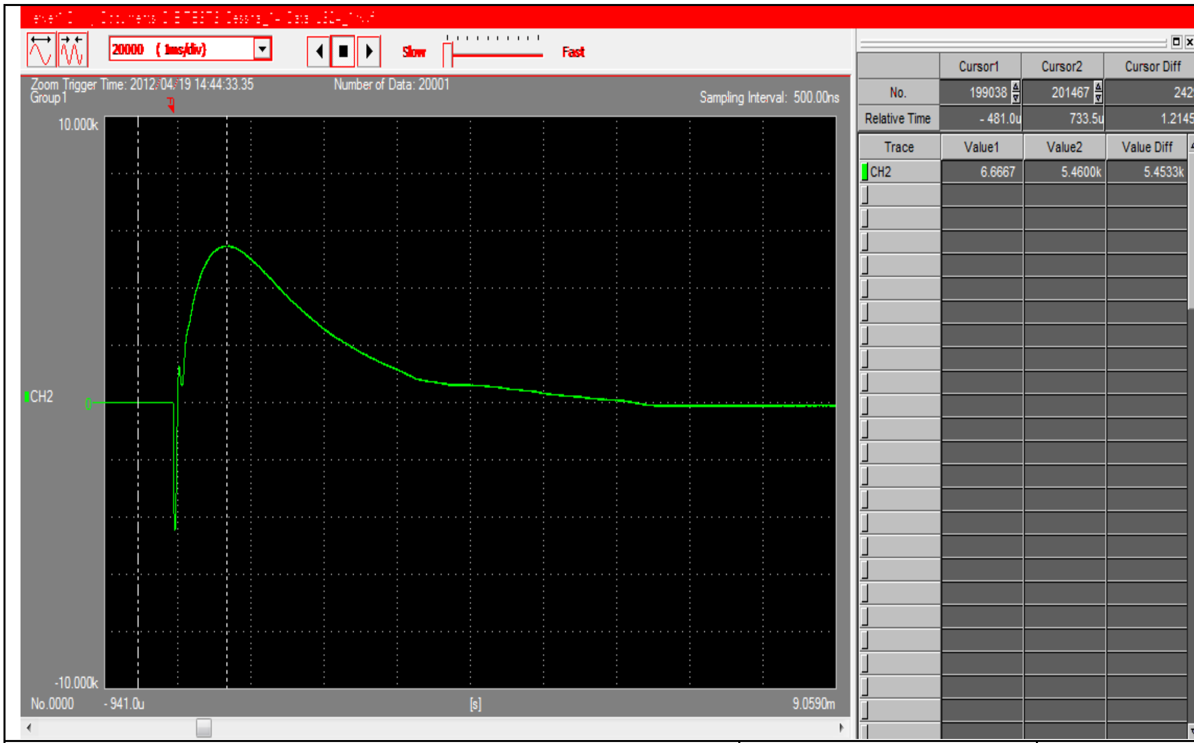


HIGH CURRENT – COMPONENT D	Ip = 95.2 KA	100 uS / Div

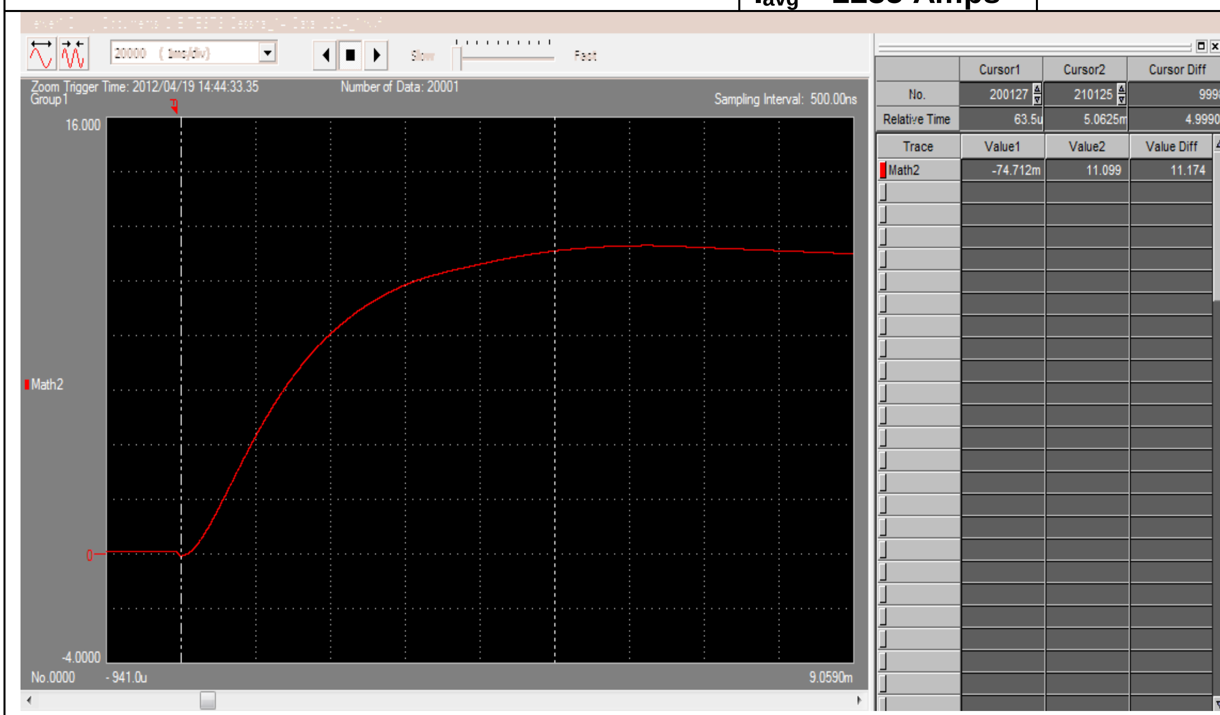


COMPONENT D ACTION INTEGRAL	AI = 275240 A^2-S

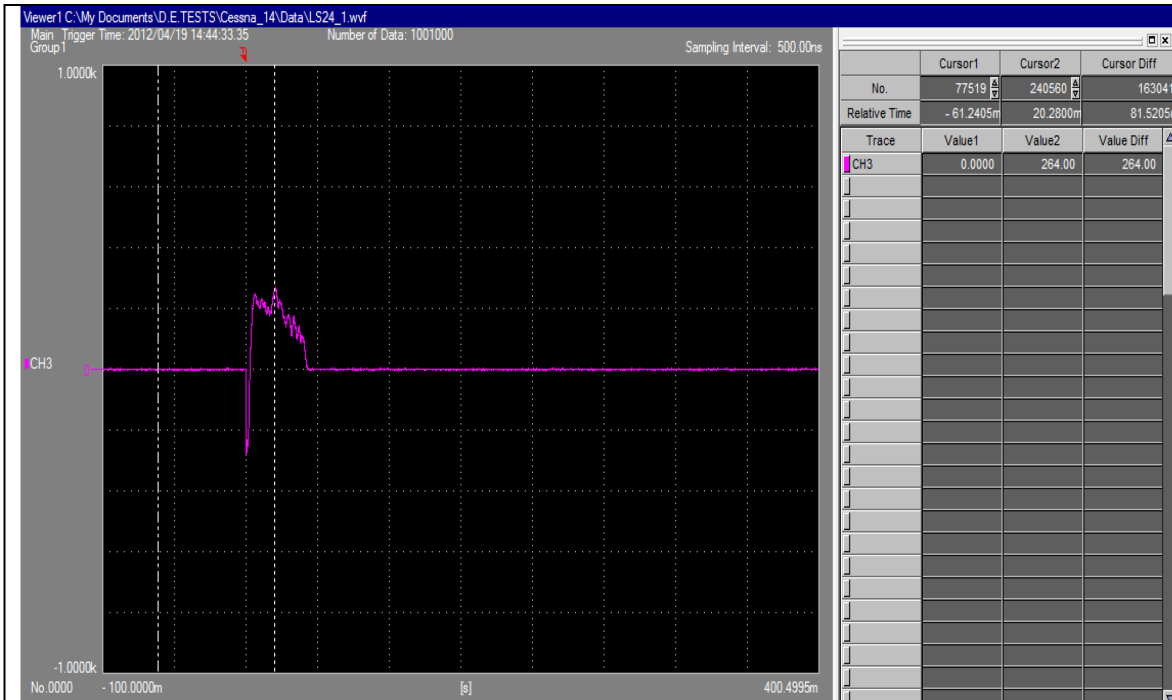
PANEL: LS-24



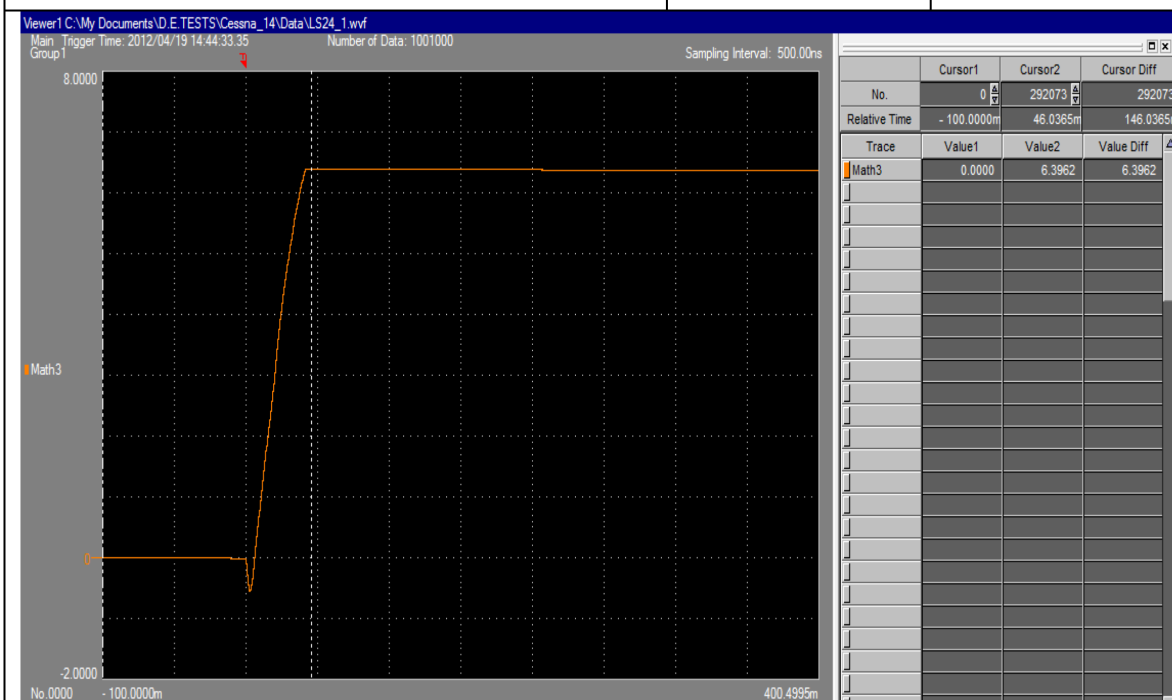
HIGH CURRENT – COMPONENT B	I_P = 5453 Amps I_{avg} = 2235 Amps	1 mS / Div



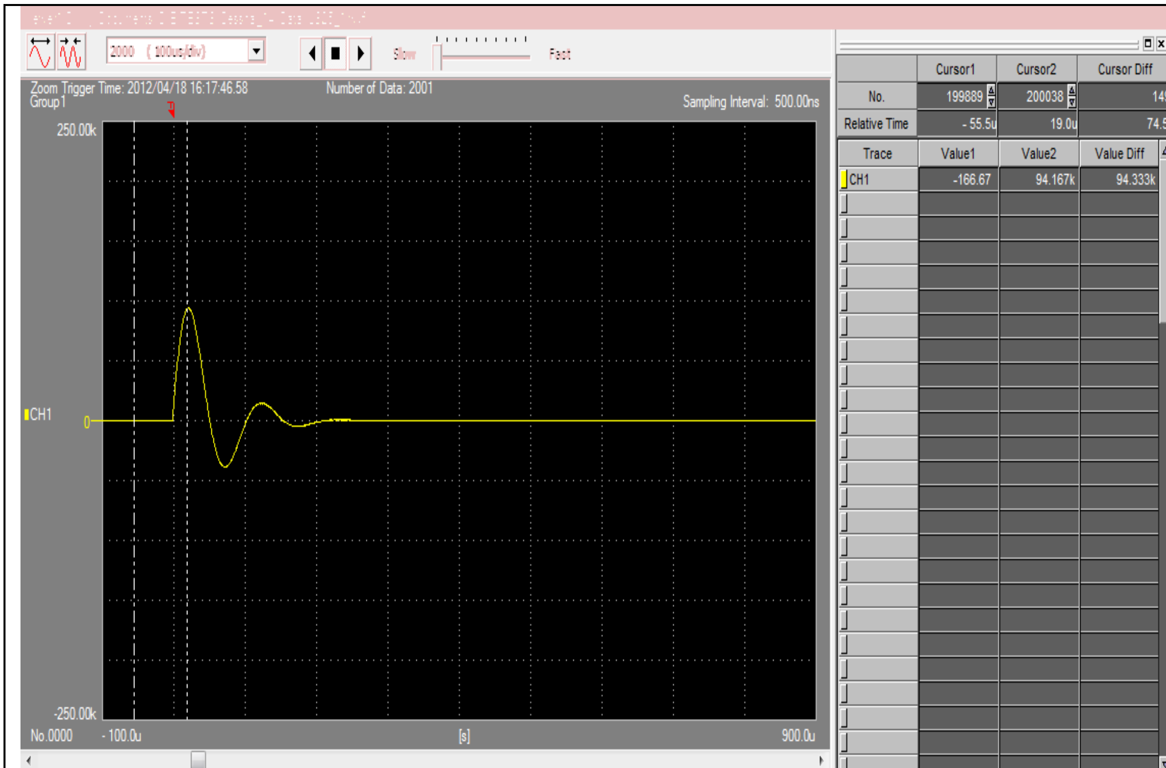
COMPONENT B CHARGE TRANSFER	11.174 Coulombs
PANEL: LS-24	



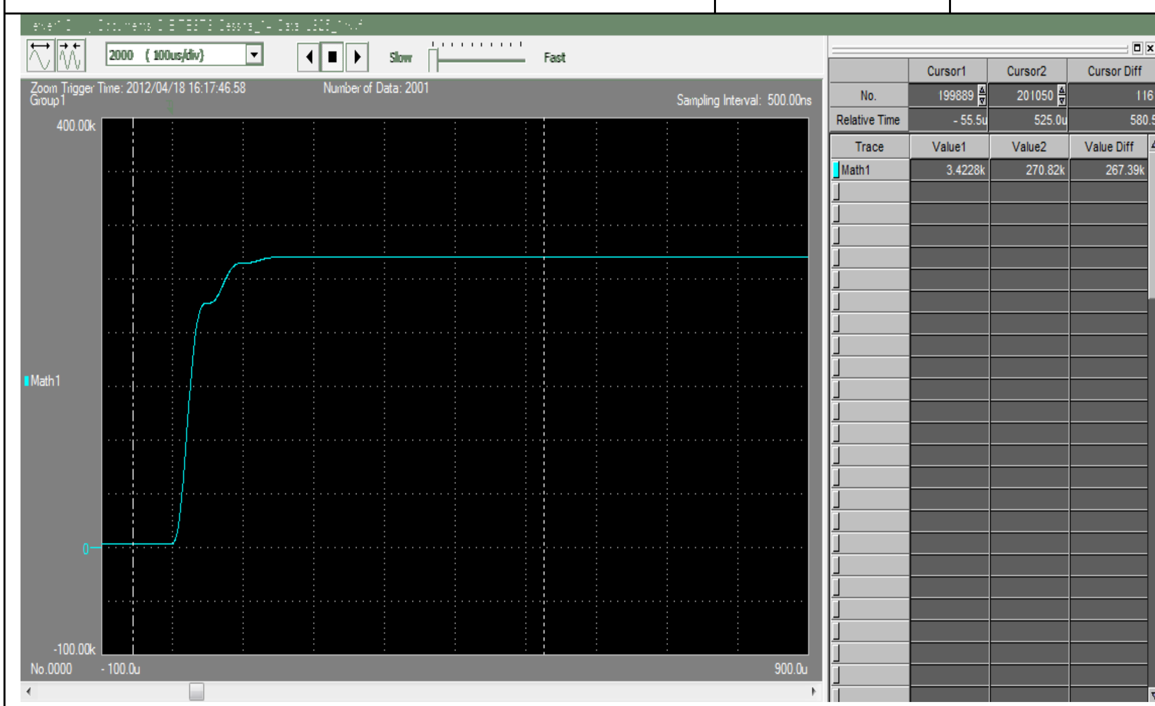
HIGH CURRENT – COMPONENT C*	Ip = 264 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	6.4 Coulombs
PANEL: LS-24	

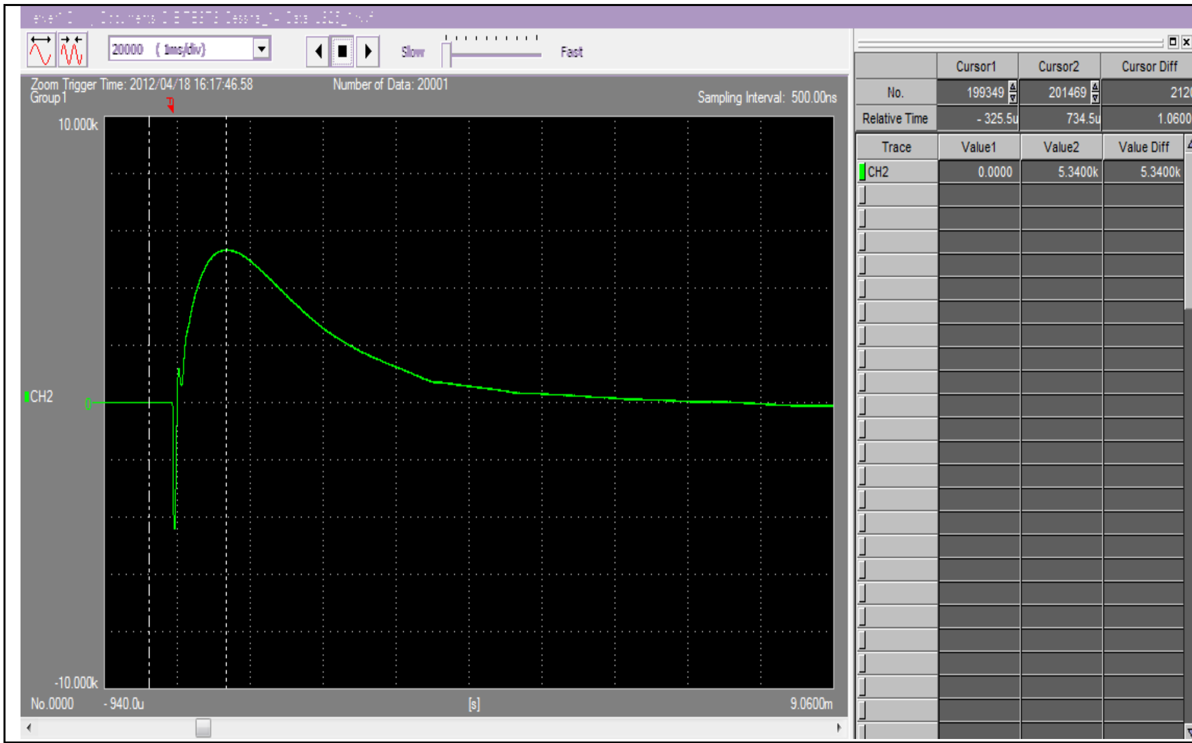


HIGH CURRENT – COMPONENT D	Ip = 94.3 KA	100 uS / Div

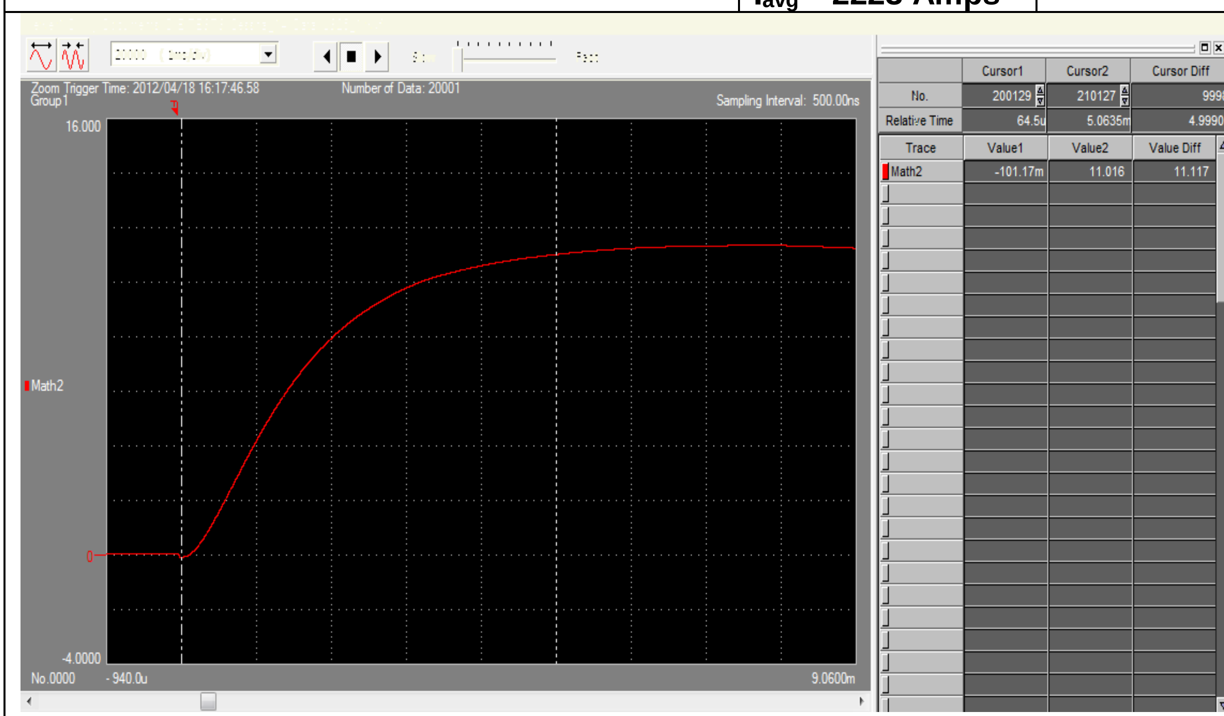


COMPONENT D ACTION INTEGRAL	AI = 267390 A^2-S

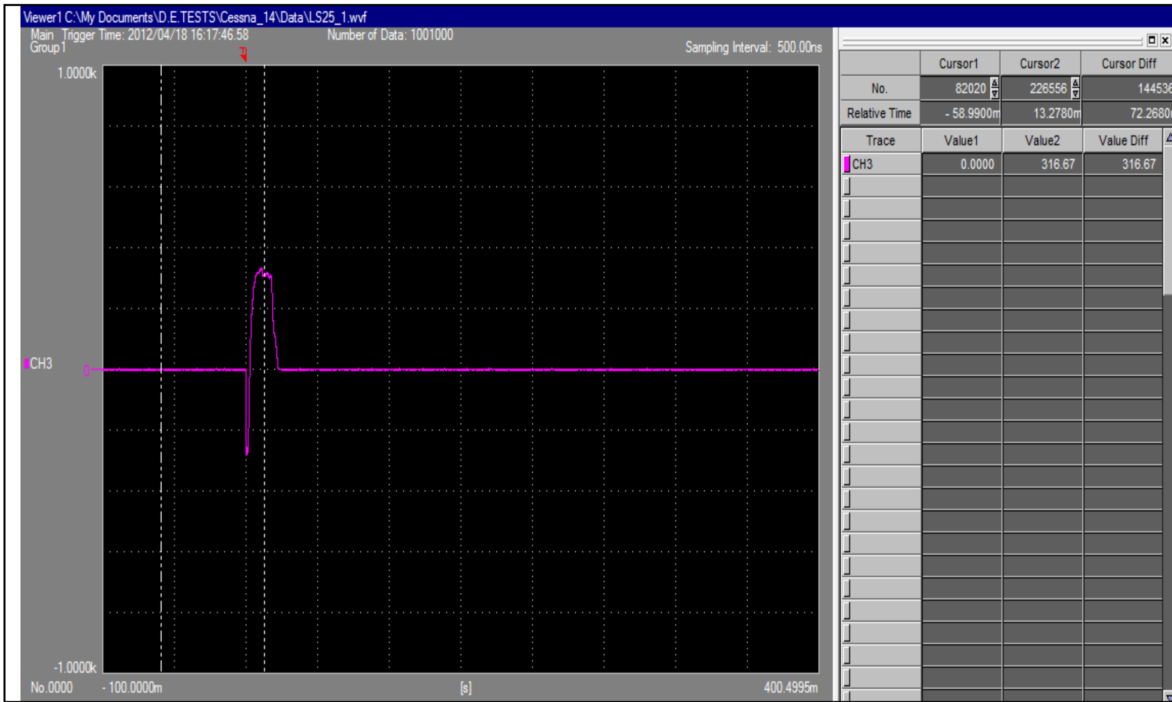
PANEL: LS-25



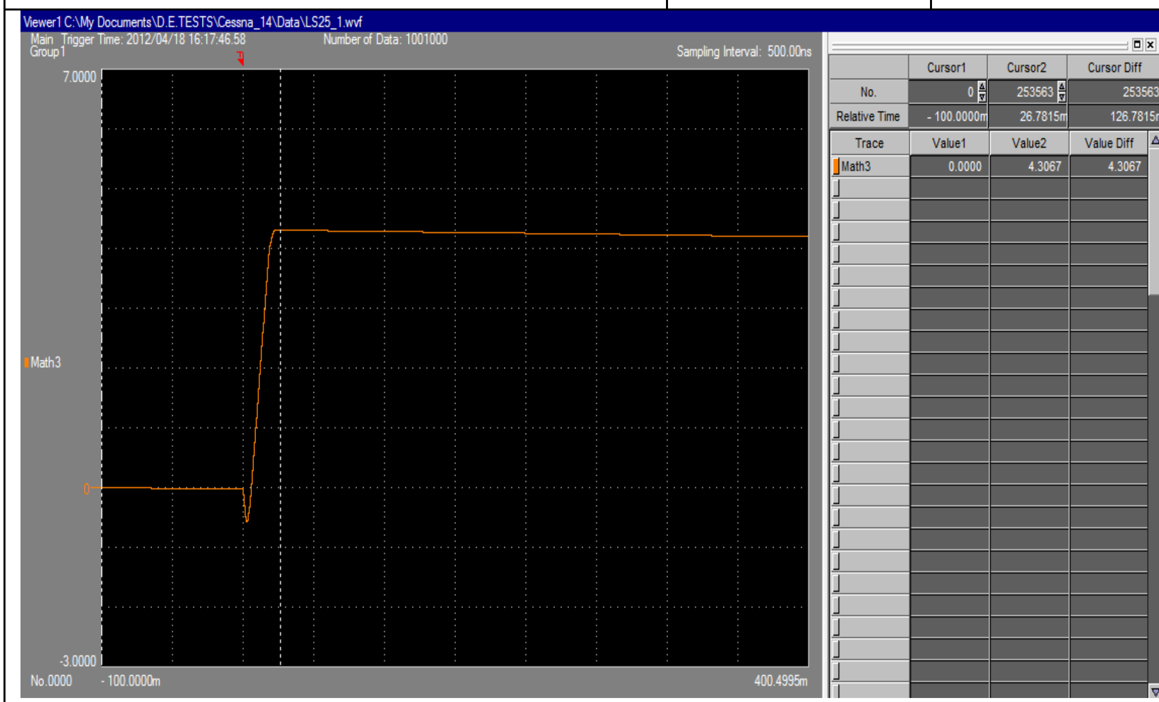
HIGH CURRENT – COMPONENT B	I_P = 5340 Amps I_{avg} = 2223 Amps	1 mS / Div



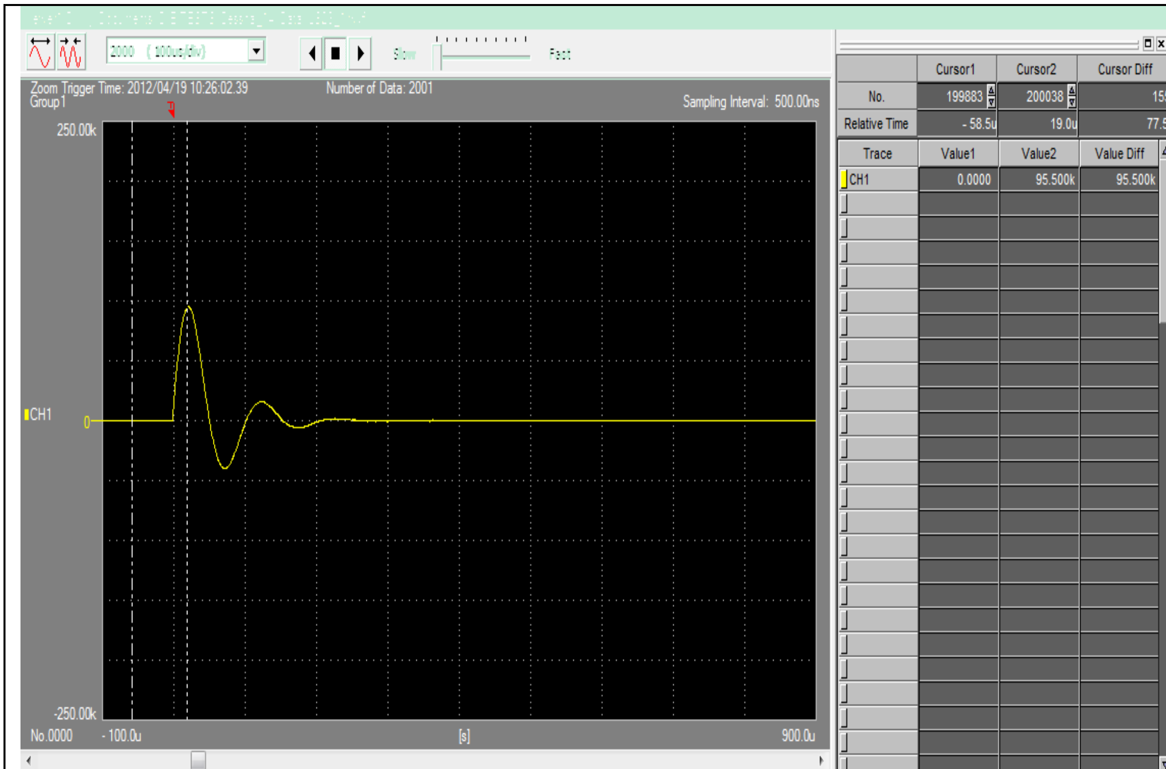
COMPONENT B CHARGE TRANSFER	11.117 Coulombs
PANEL: LS-25	



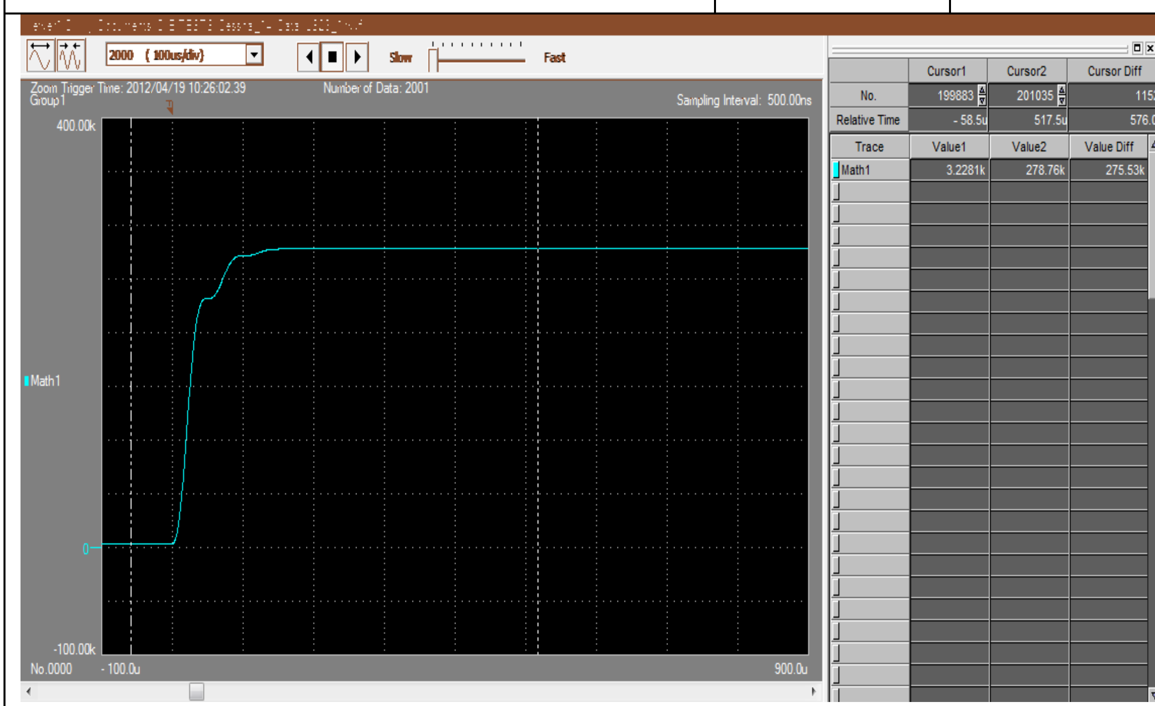
HIGH CURRENT – COMPONENT C*	Ip = 317 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	4.3 Coulombs
PANEL: LS-25	

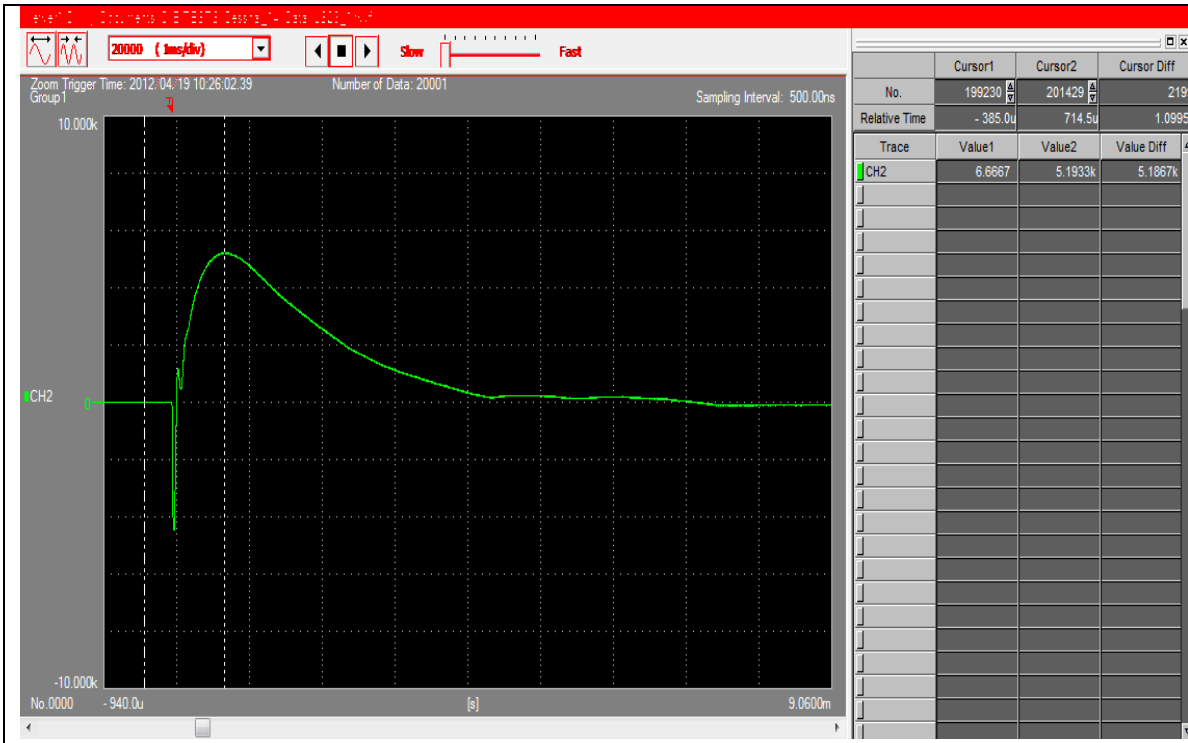


HIGH CURRENT – COMPONENT D	Ip = 95.5 KA	100 uS / Div

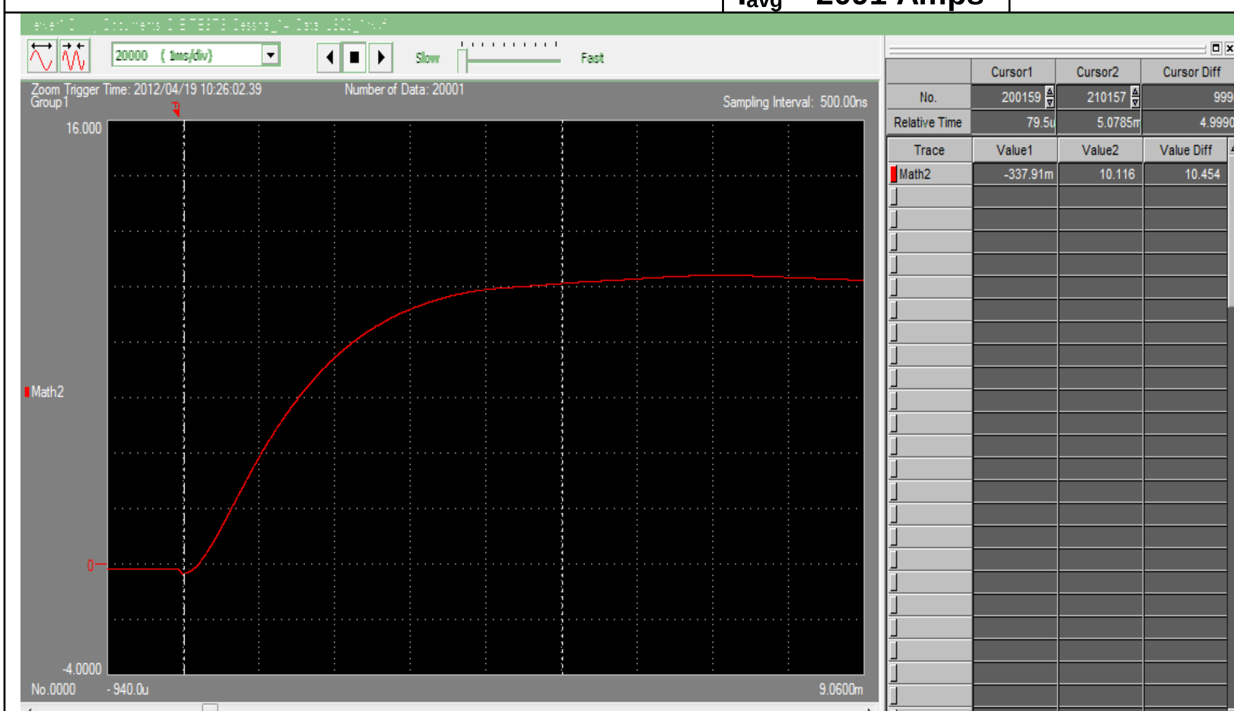


COMPONENT D ACTION INTEGRAL	AI = 275530 A^2-S

PANEL: LS-26

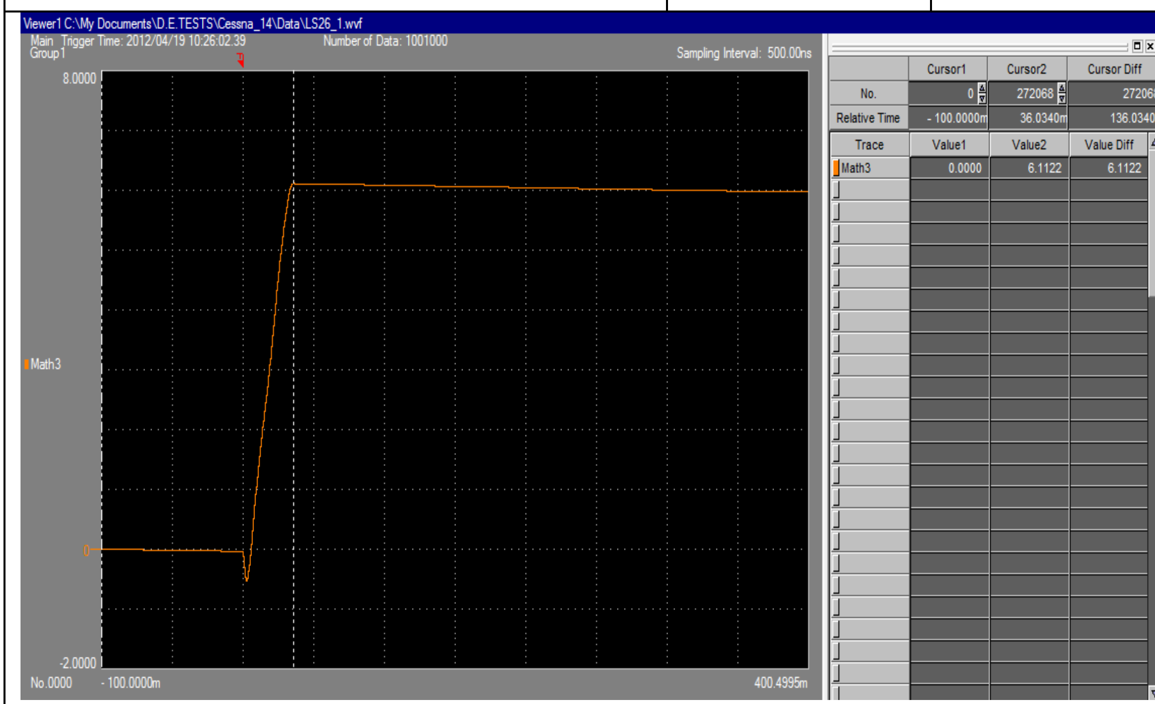


HIGH CURRENT – COMPONENT B	I_P = 5187 Amps I_{avg} = 2091 Amps	1 mS / Div



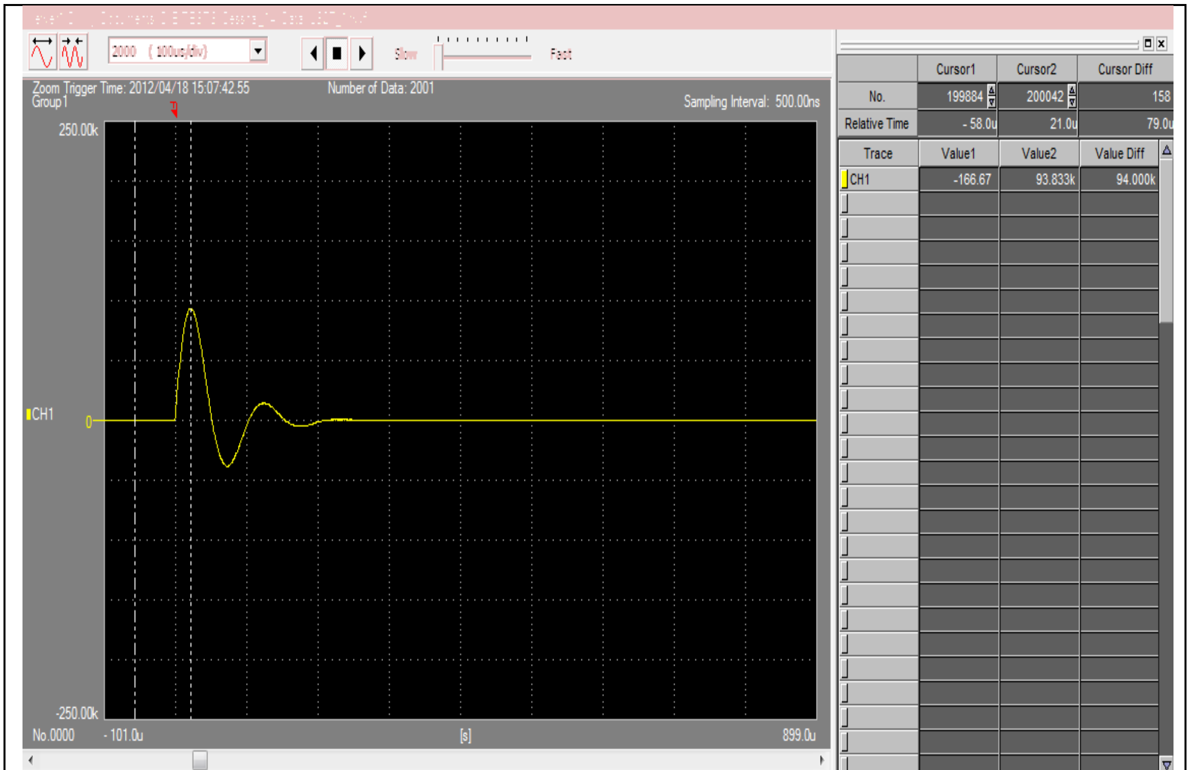
COMPONENT B CHARGE TRANSFER	10.454 Coulombs
PANEL: LS-26	

HIGH CURRENT – COMPONENT C*	Ip = 294 Amps	50 mS / Div

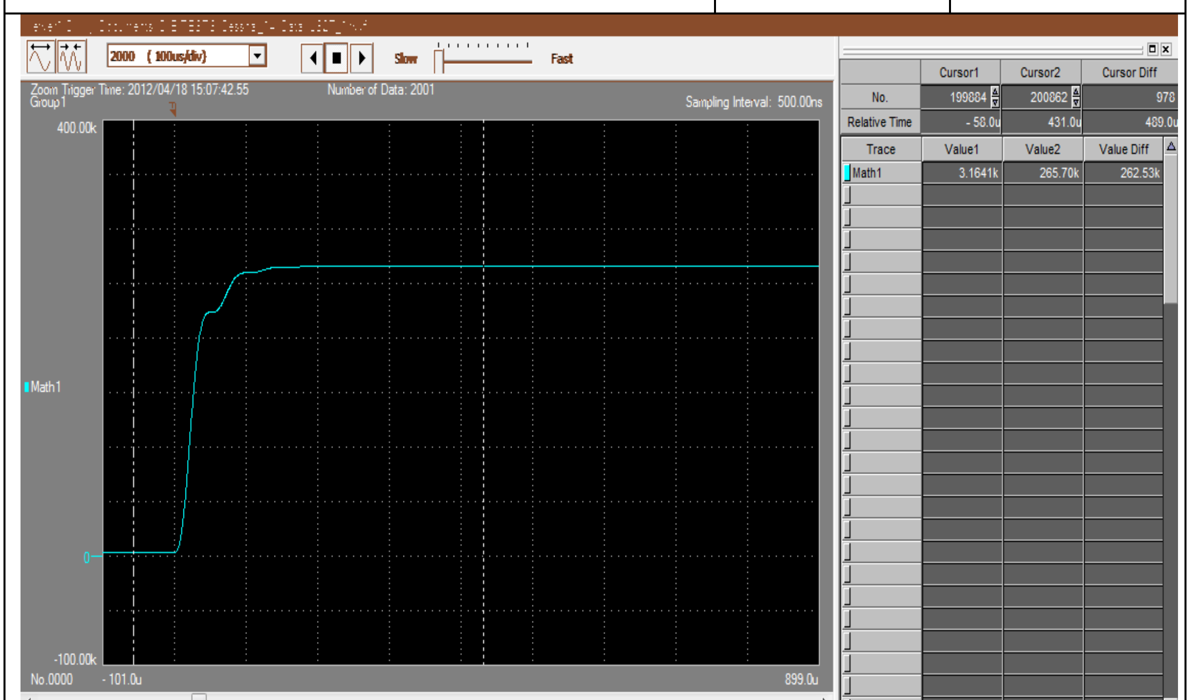


COMPONENT C* CHARGE TRANSFER	6.1 Coulombs

PANEL: LS-26

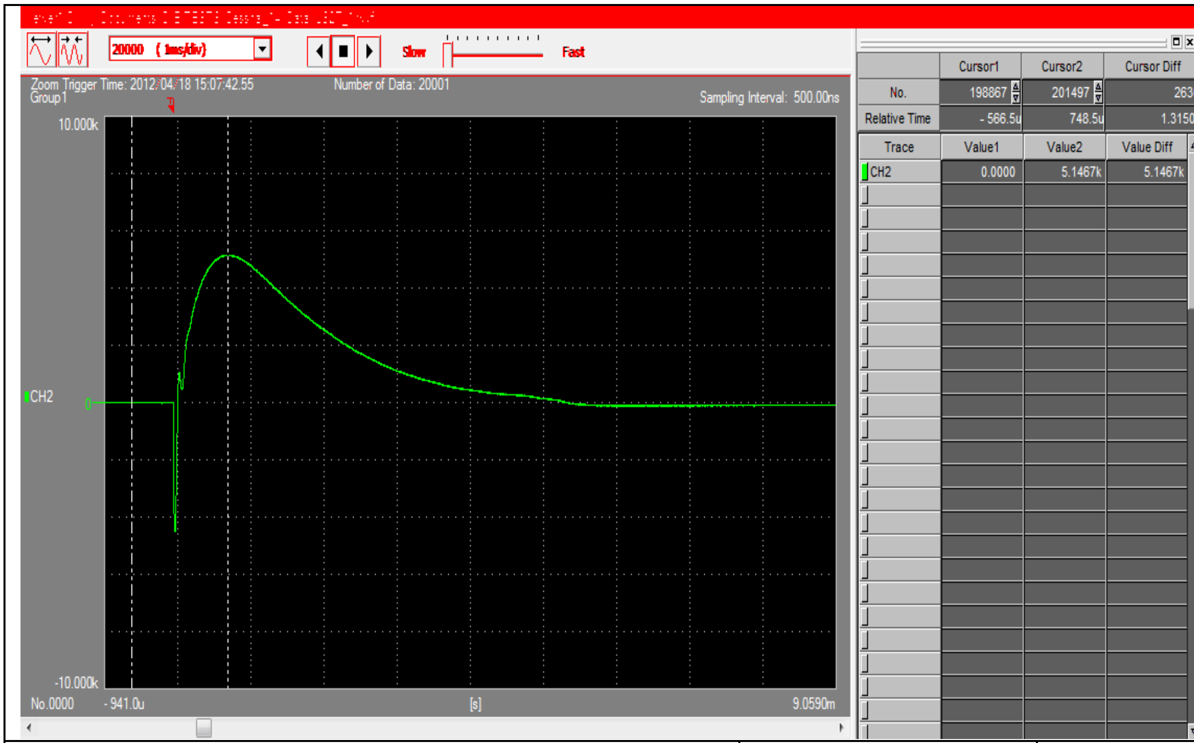


HIGH CURRENT – COMPONENT D	Ip = 94.0 KA	100 uS / Div

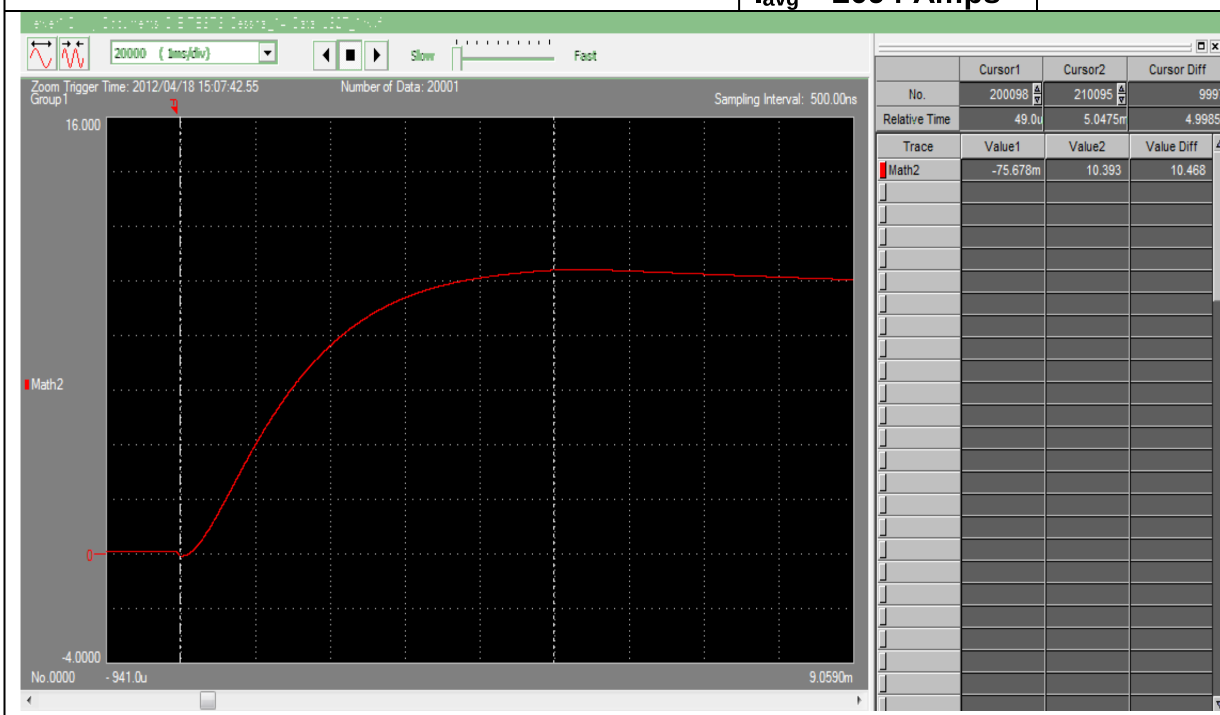


COMPONENT D ACTION INTEGRAL	AI = 262530 A^2-S

PANEL: LS-27

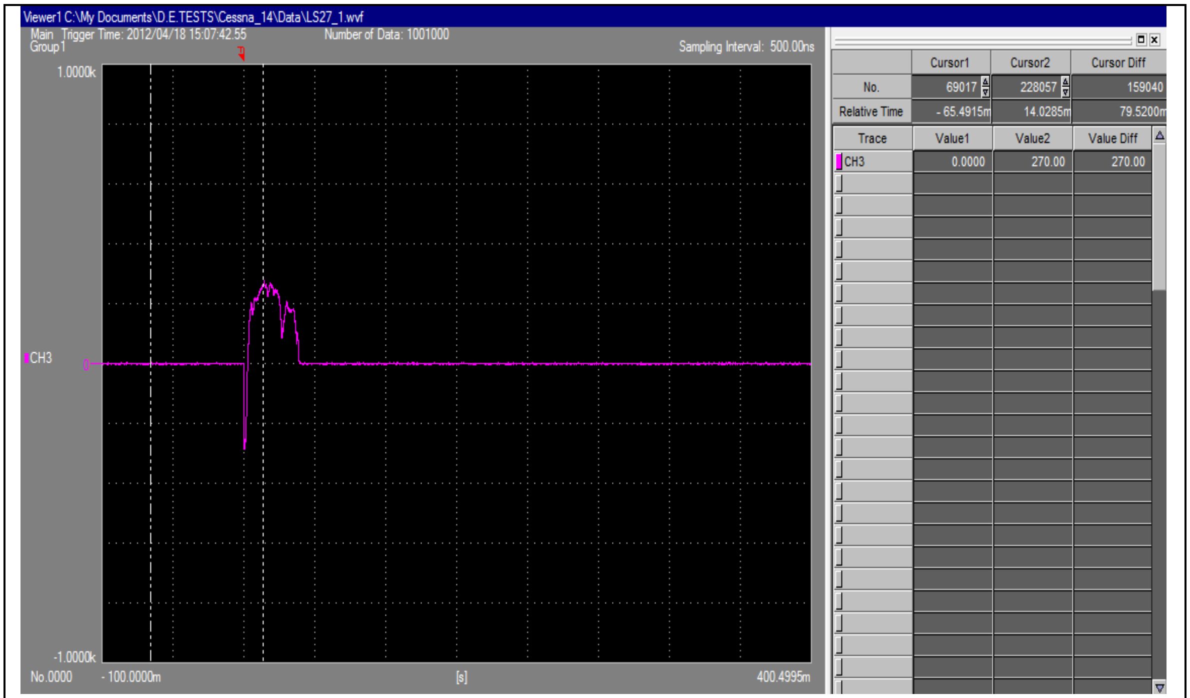


HIGH CURRENT – COMPONENT B	I_P = 5147 Amps I_{avg} = 2094 Amps	1 mS / Div

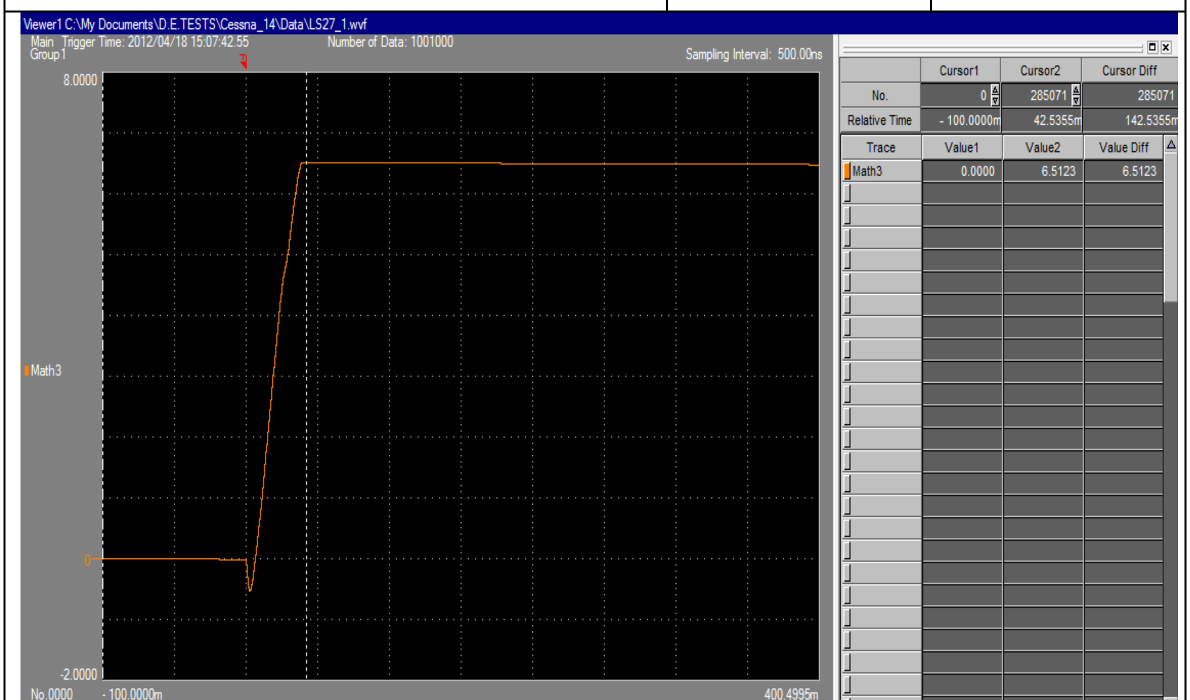


COMPONENT B CHARGE TRANSFER	10.468 Coulombs

PANEL: LS-27

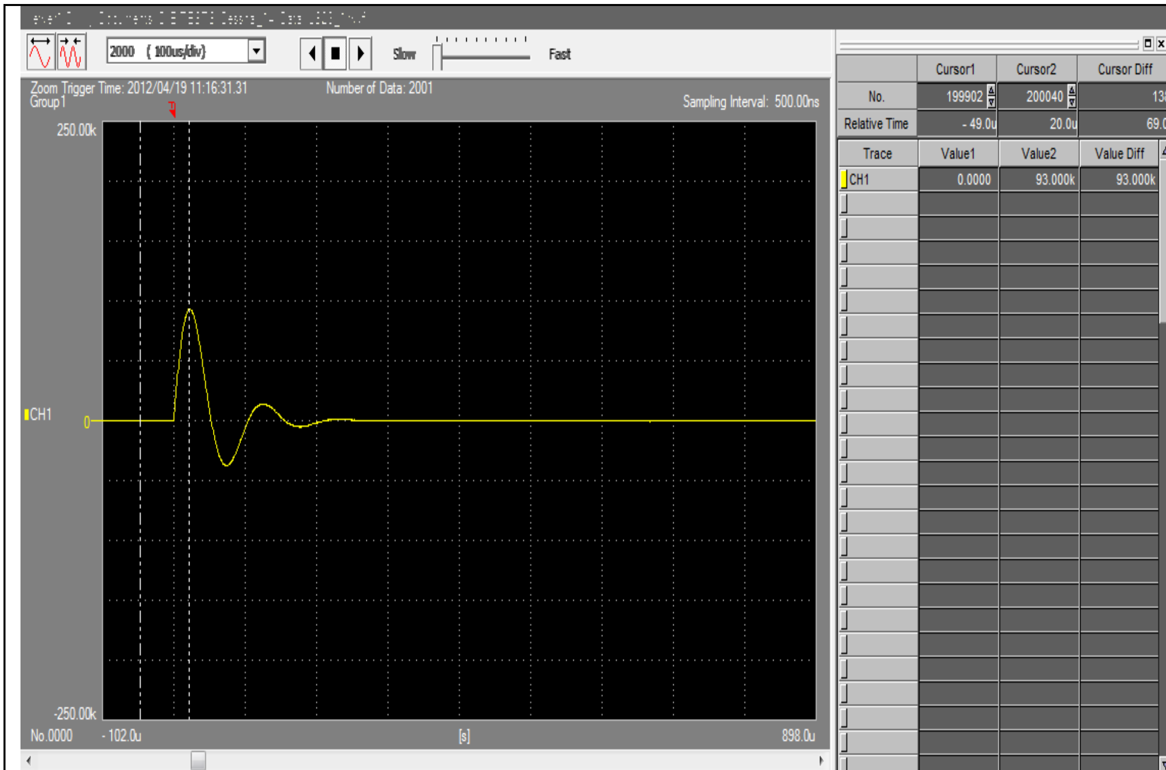


HIGH CURRENT – COMPONENT C*	Ip = 270 Amps	50 mS / Div

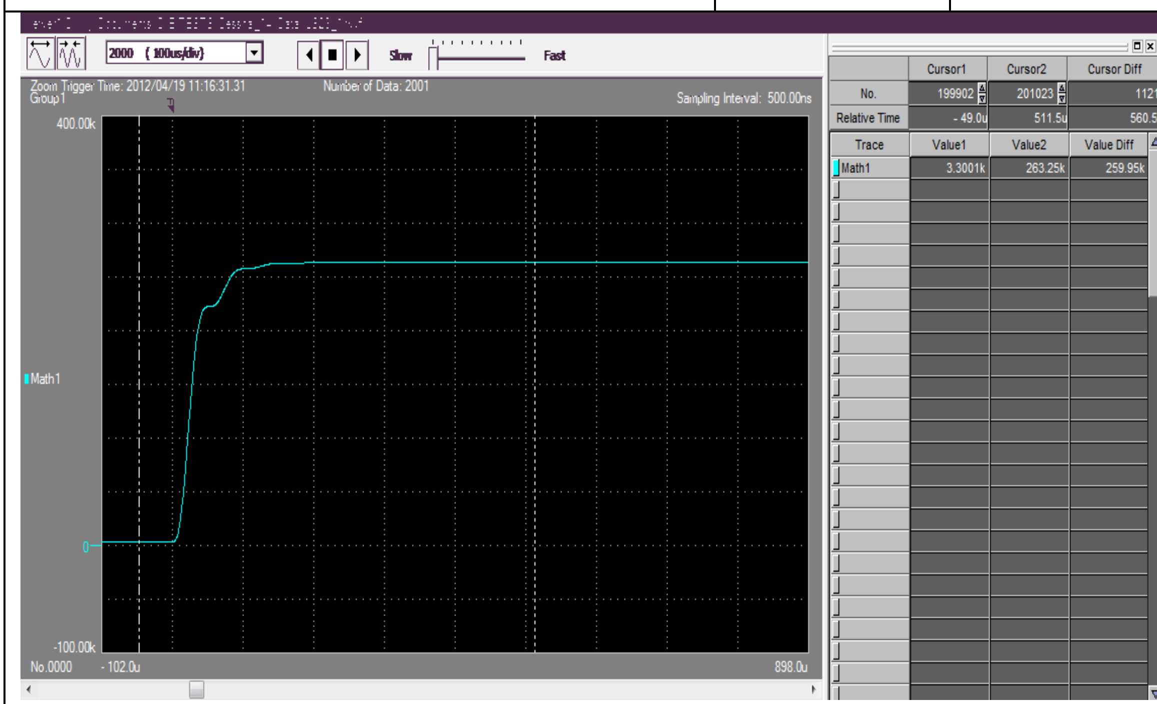


COMPONENT C* CHARGE TRANSFER	6.5 Coulombs

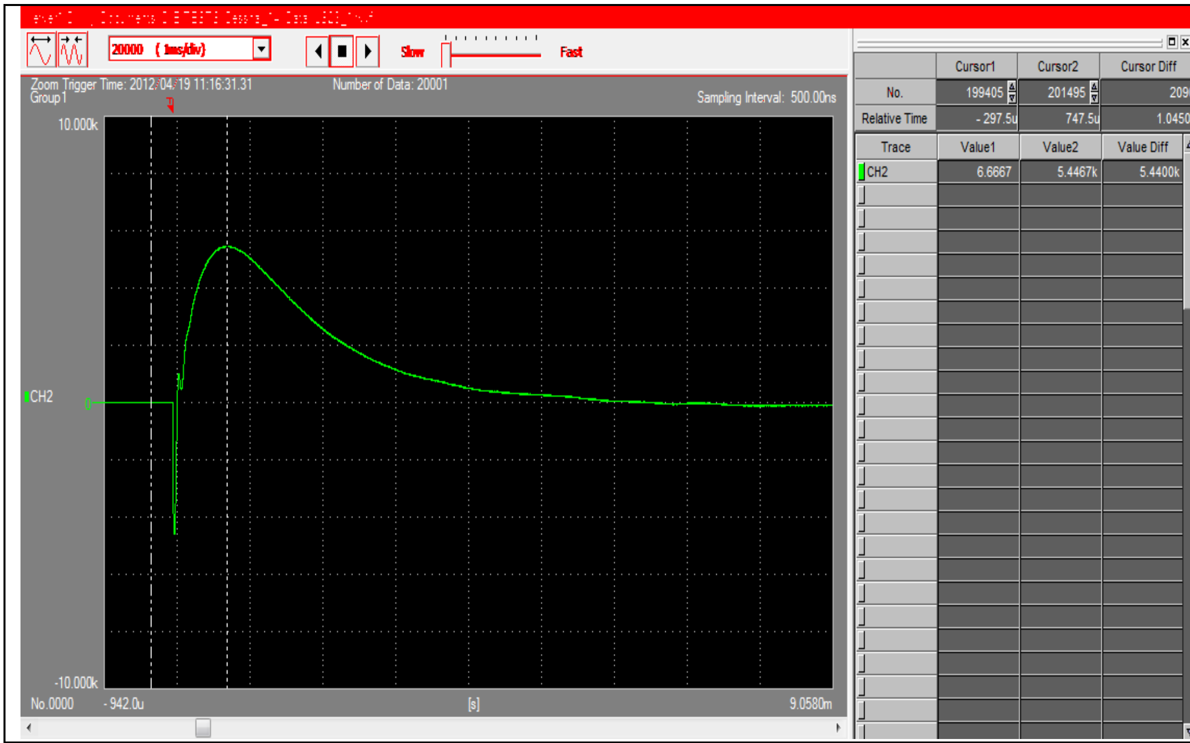
PANEL: LS-27



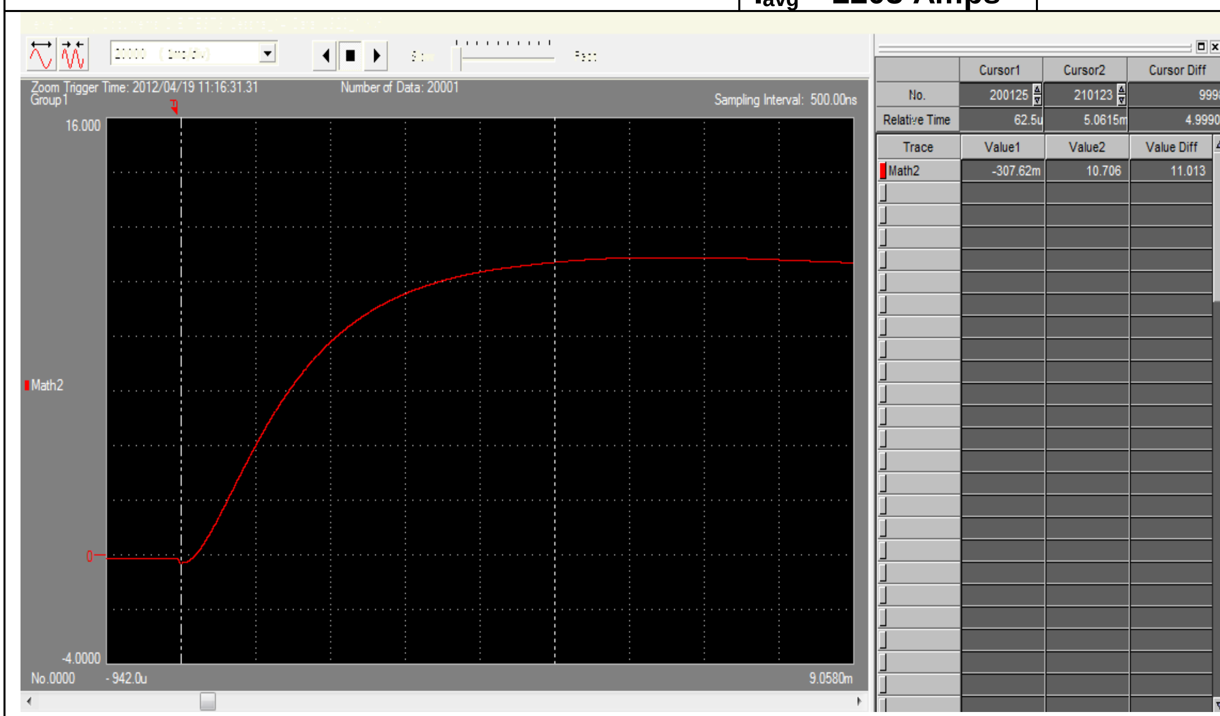
HIGH CURRENT – COMPONENT D	Ip = 93.0 KA	100 uS / Div



COMPONENT D ACTION INTEGRAL	AI = 259950 A^2-S
PANEL: LS-28	

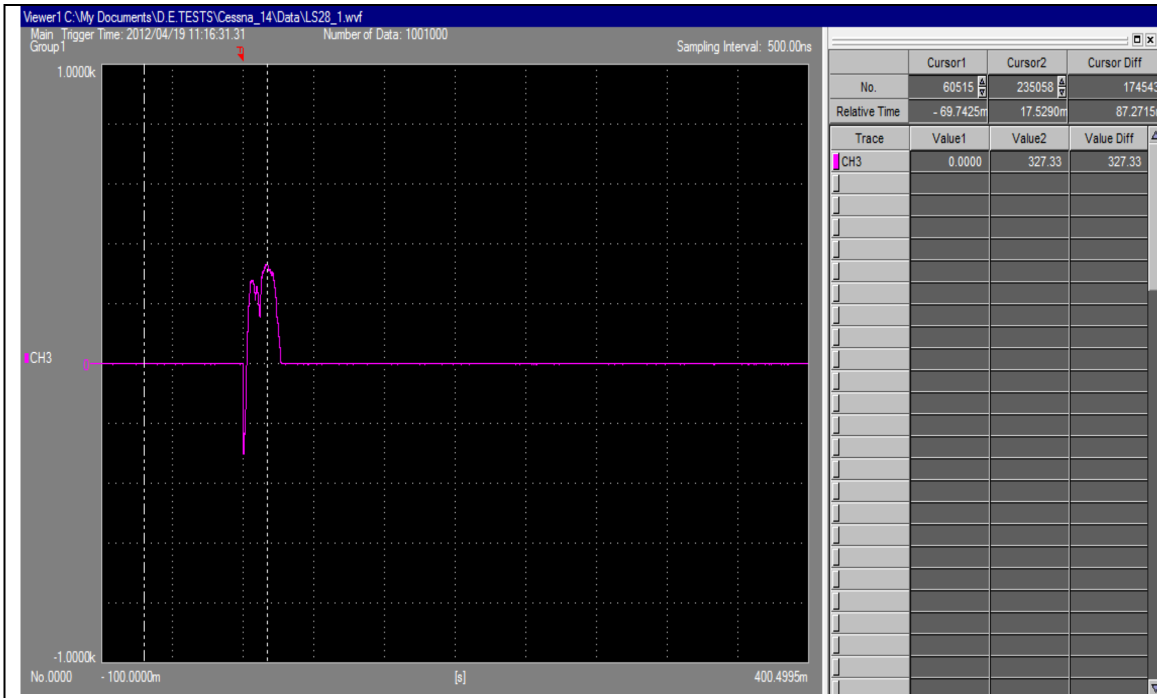


HIGH CURRENT – COMPONENT B	I_P = 5440 Amps I_{avg} = 2203 Amps	1 mS / Div

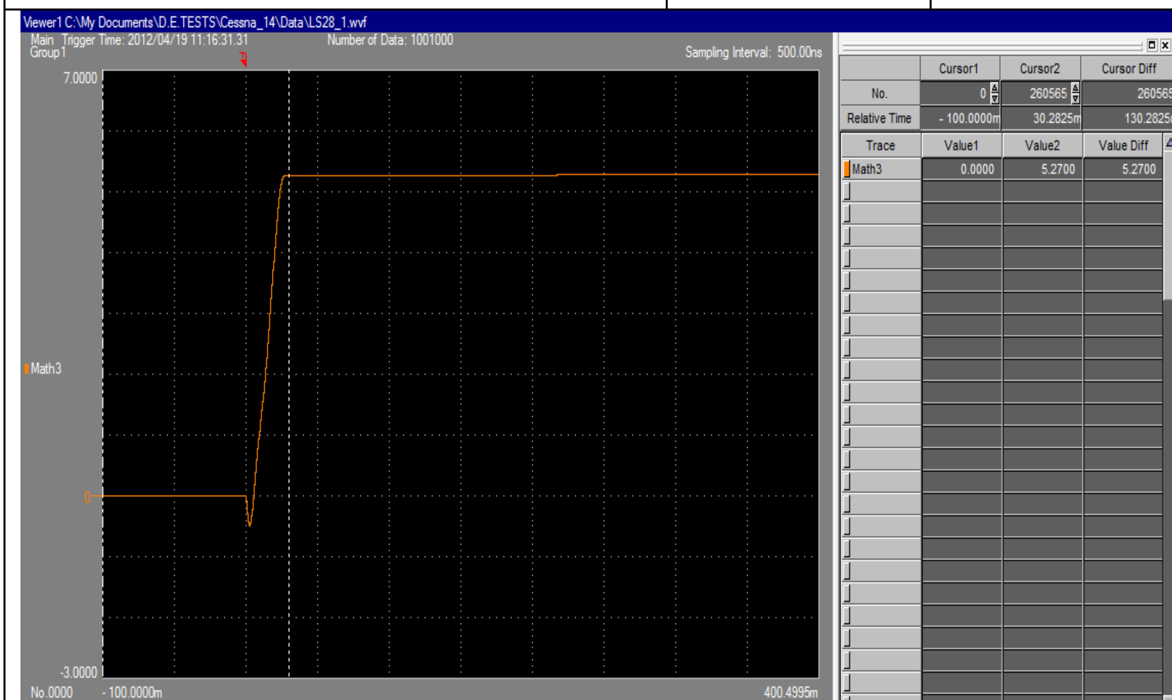


COMPONENT B CHARGE TRANSFER	11.013 Coulombs

PANEL: LS-28

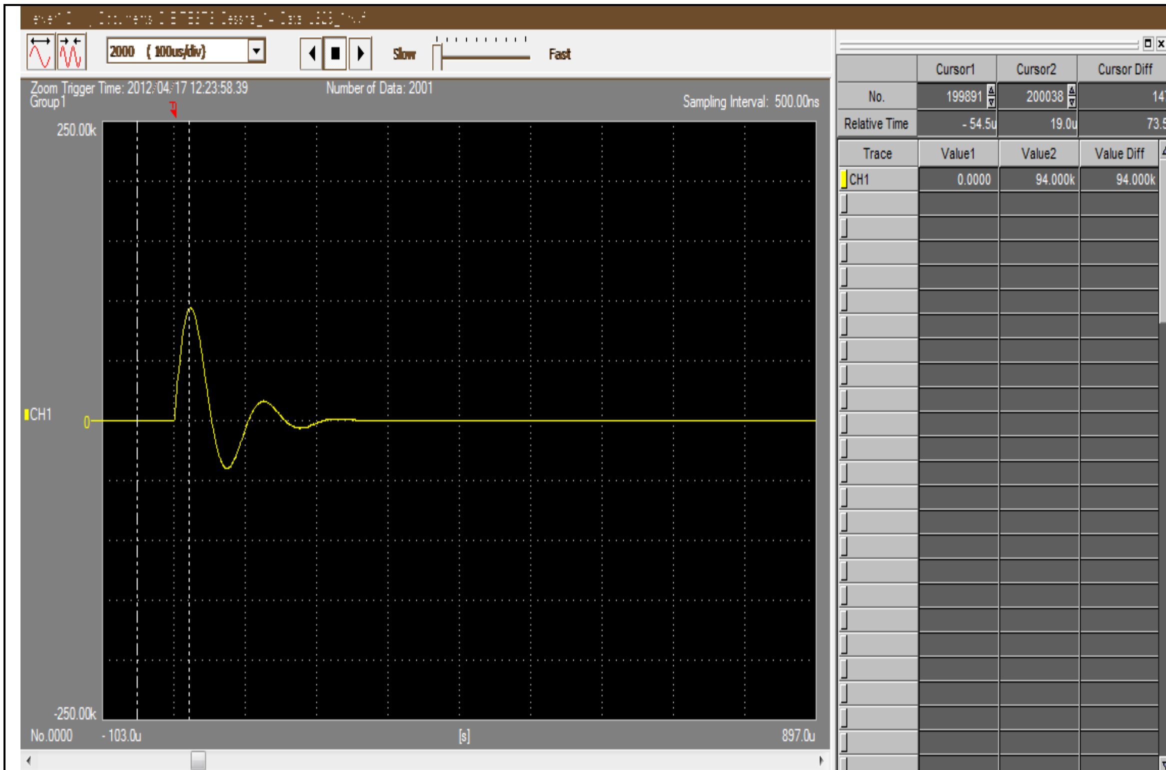


HIGH CURRENT – COMPONENT C*	Ip = 327 Amps	50 mS / Div

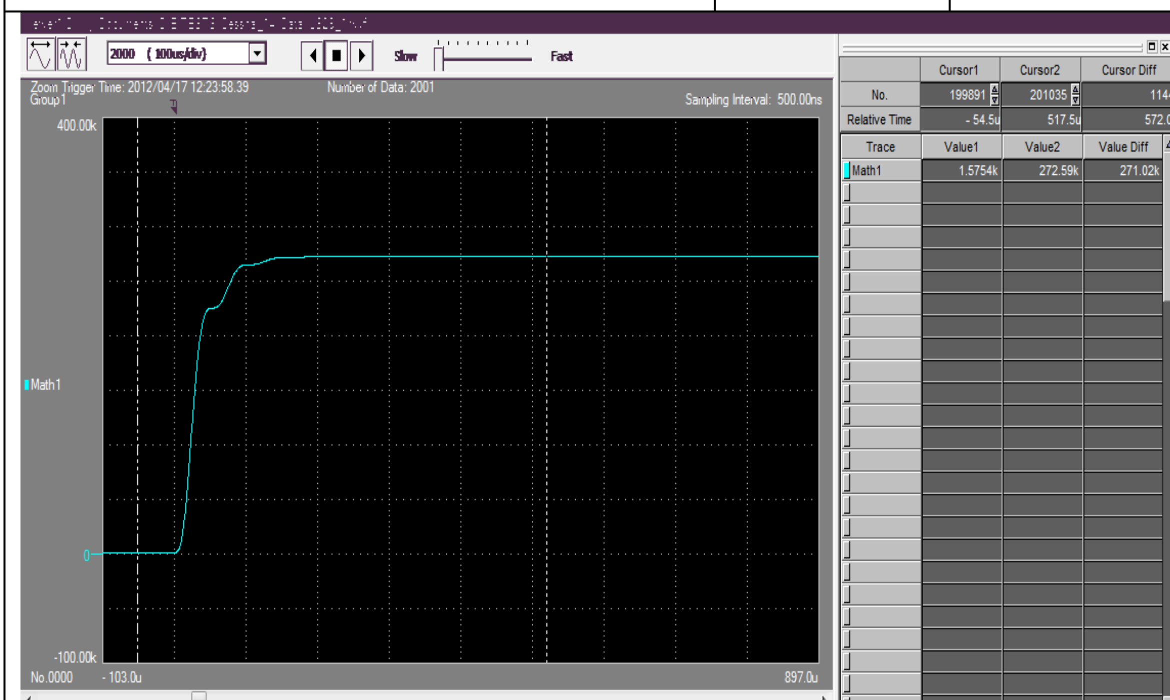


COMPONENT C* CHARGE TRANSFER	5.3 Coulombs

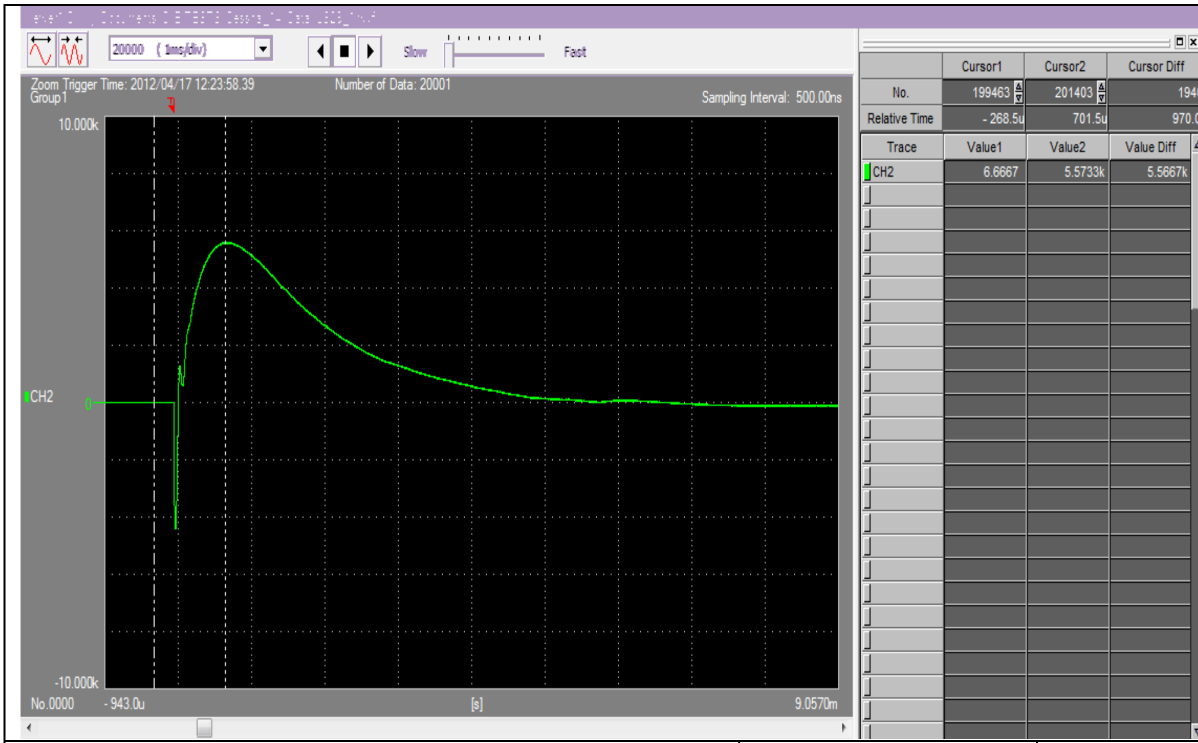
PANEL: LS-28



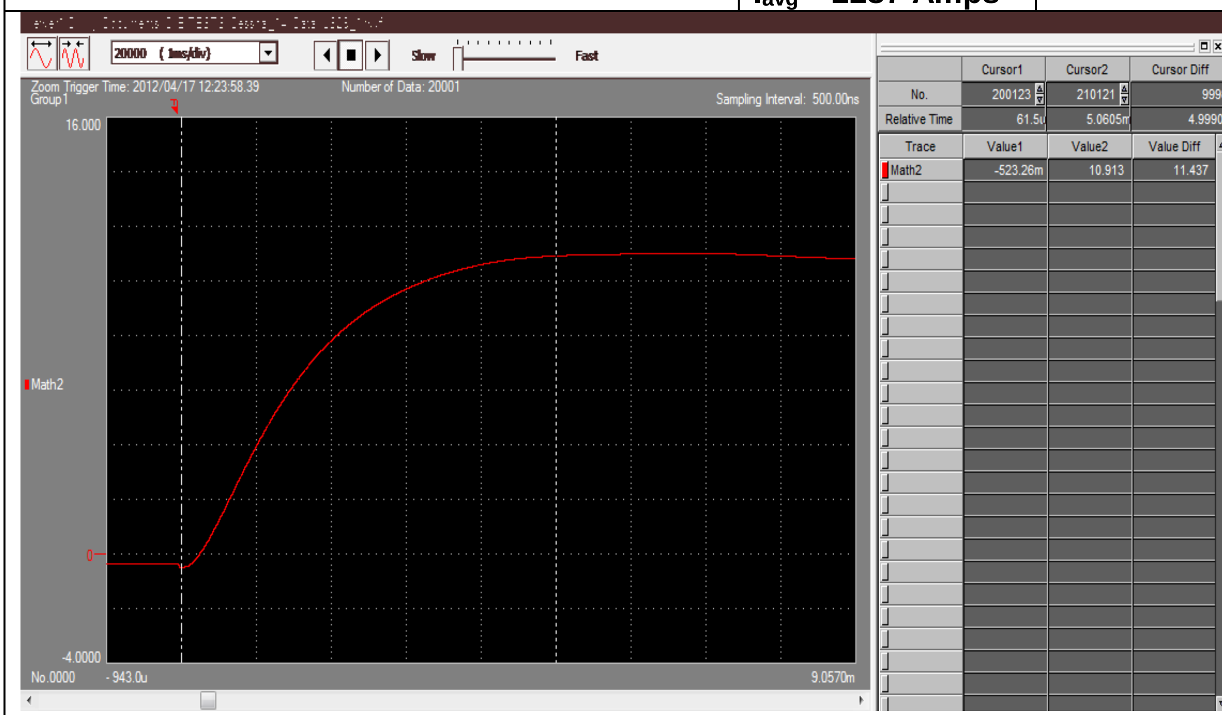
HIGH CURRENT – COMPONENT D	Ip = 94.0 KA	100 uS / Div



COMPONENT D ACTION INTEGRAL	AI = 271020 A^2-S
PANEL: LS-29	

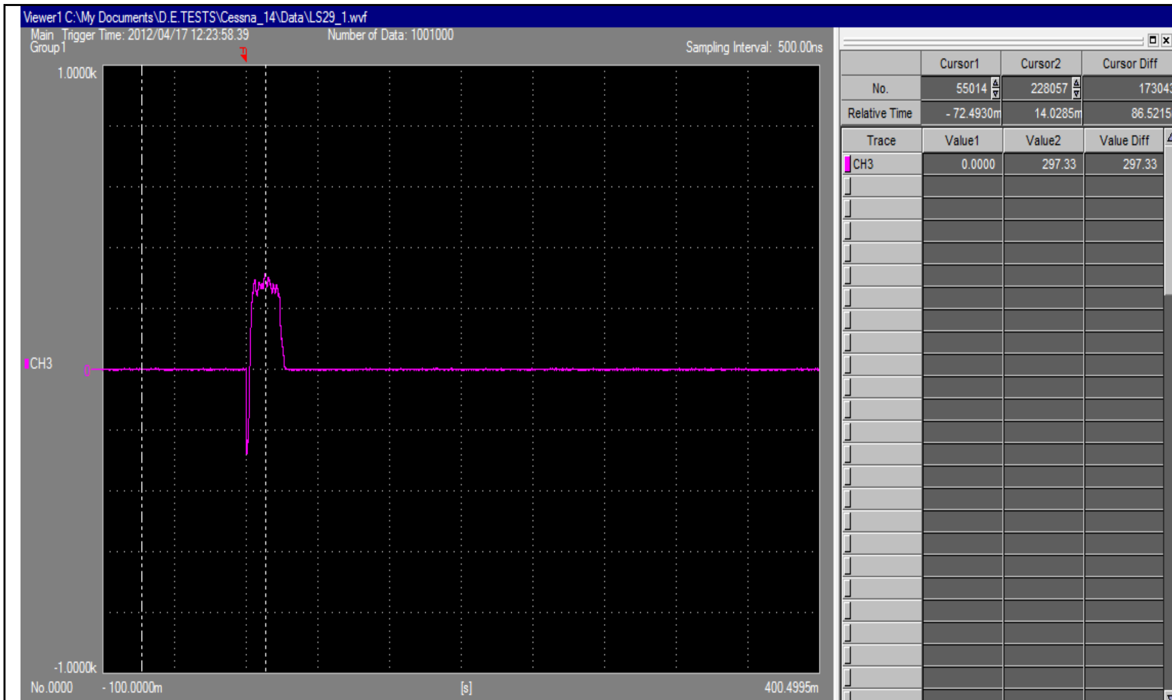


HIGH CURRENT – COMPONENT B	I_P = 5567 Amps I_{avg} = 2287 Amps	1 mS / Div

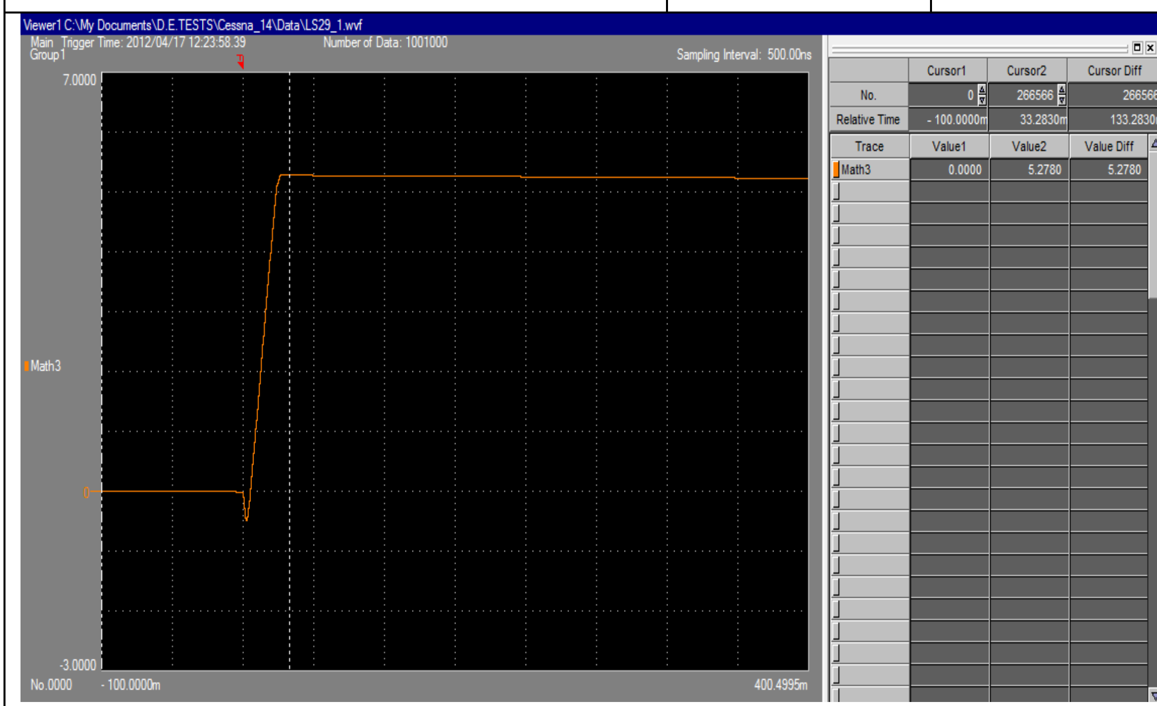


COMPONENT B CHARGE TRANSFER	11.437 Coulombs

PANEL: LS-29

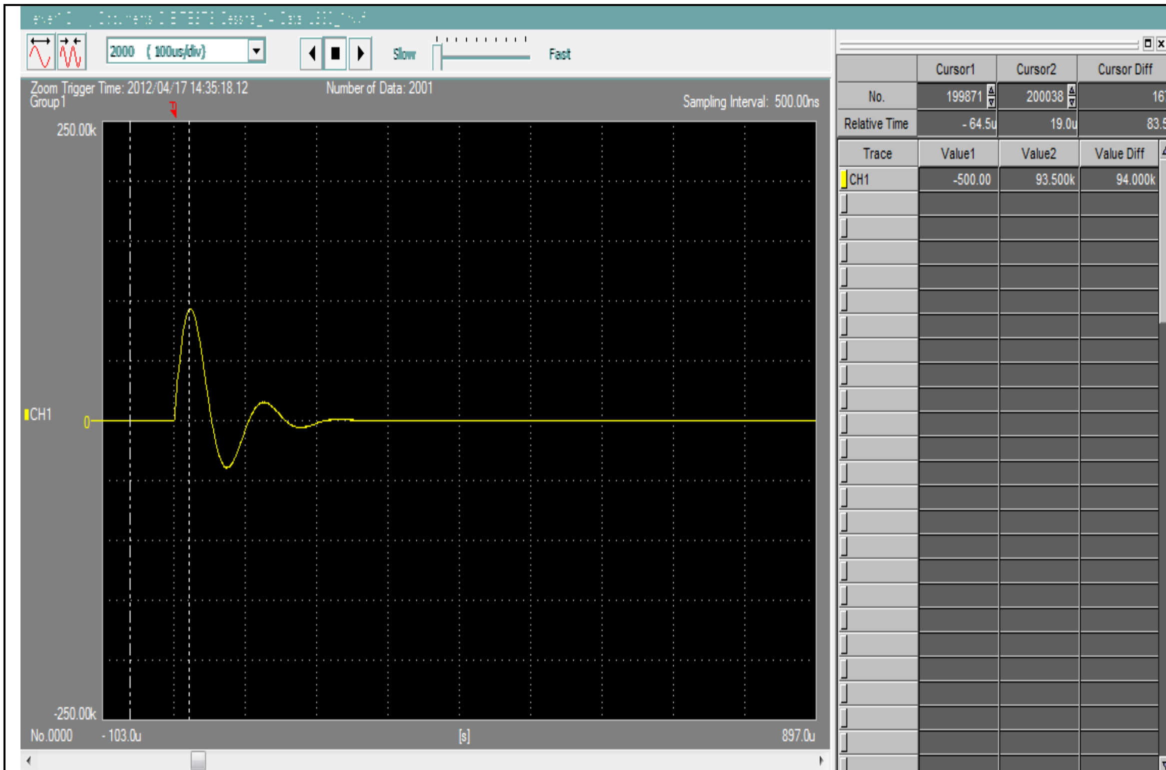


HIGH CURRENT – COMPONENT C*	Ip = 297 Amps	50 mS / Div

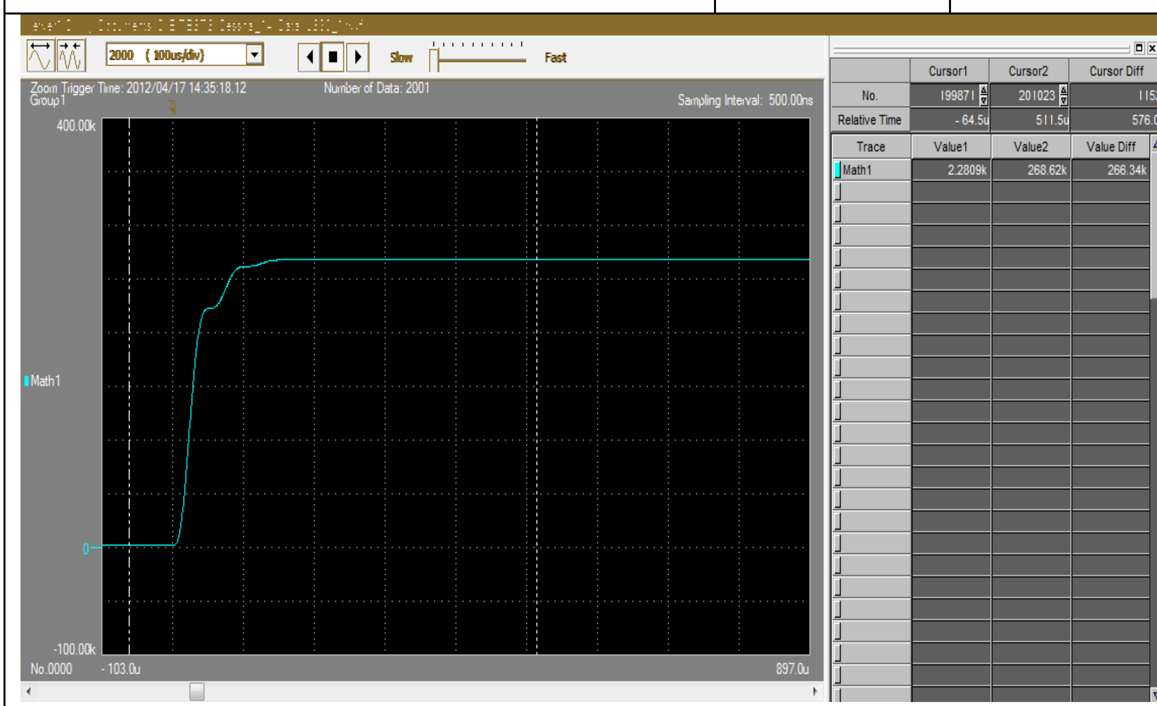


COMPONENT C* CHARGE TRANSFER	5.3 Coulombs

PANEL: LS-29

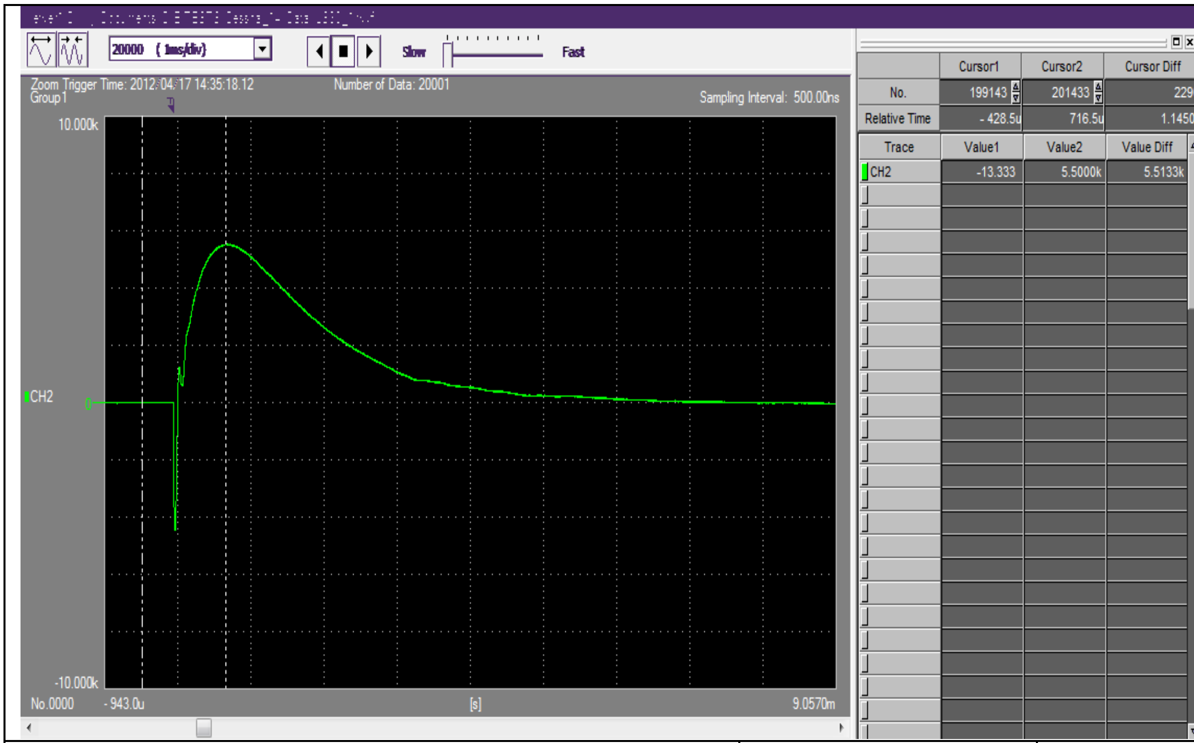


HIGH CURRENT – COMPONENT D	Ip = 94.0 KA	100 uS / Div

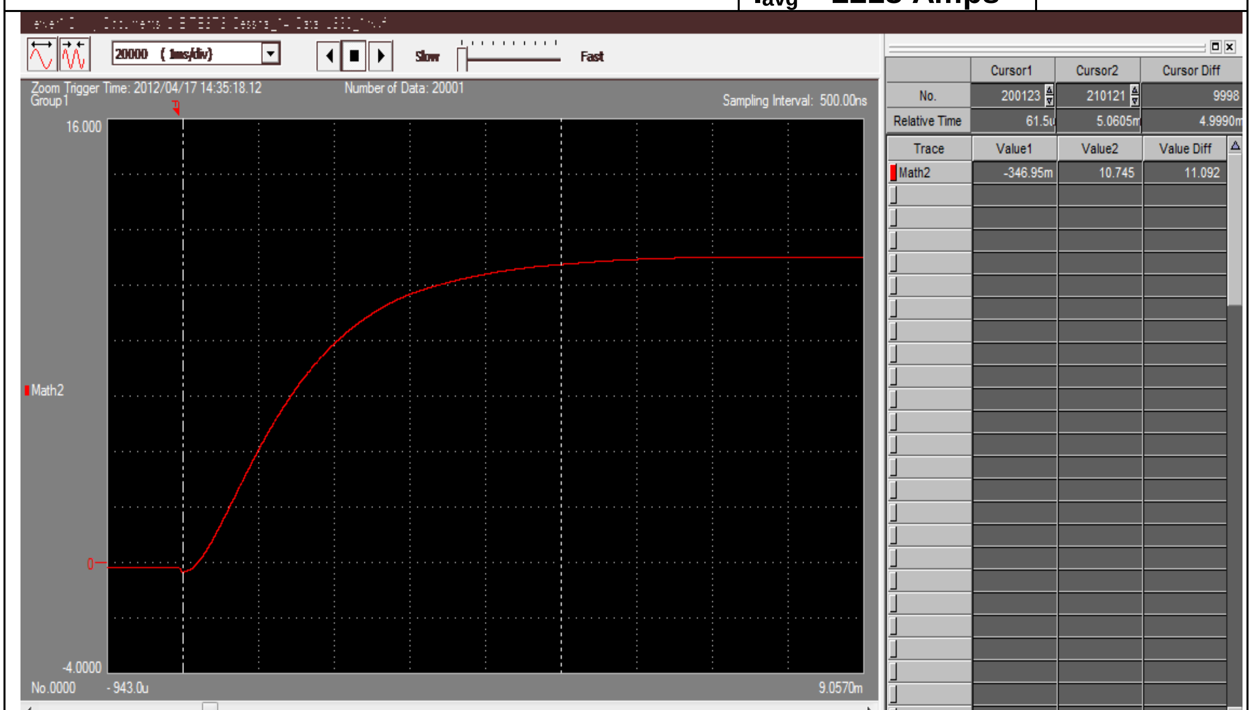


COMPONENT D ACTION INTEGRAL	AI = 266340 A^2-S

PANEL: LS-30

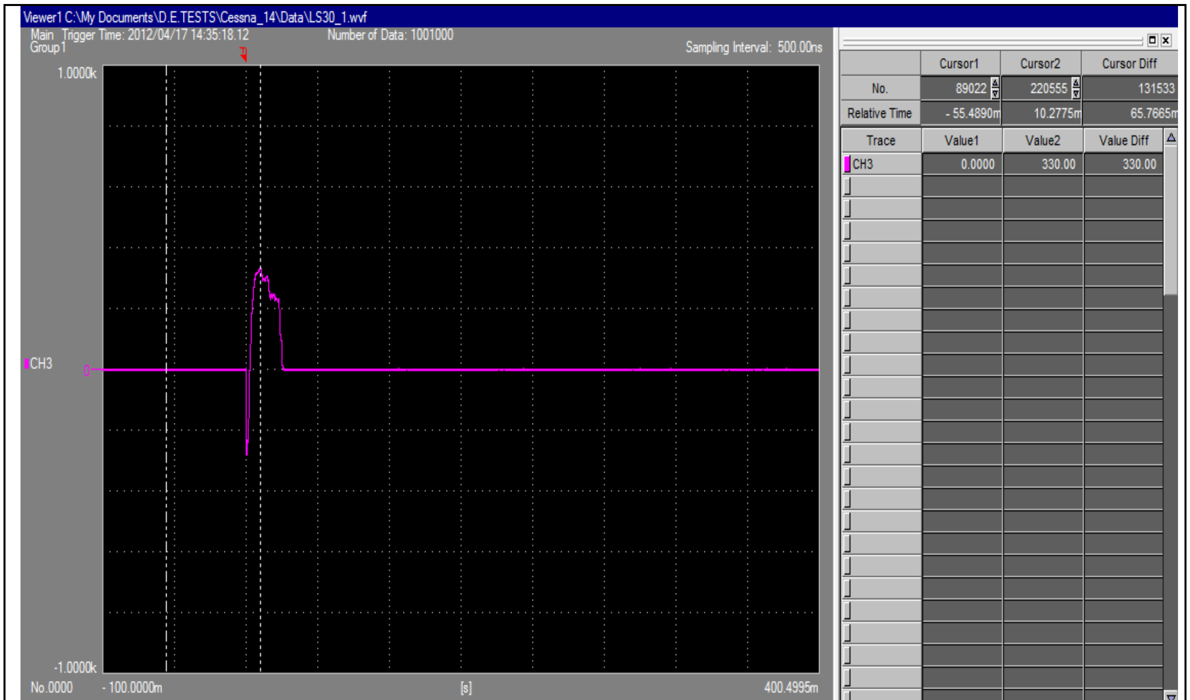


HIGH CURRENT – COMPONENT B	**I_P = 5513 Amps** **I_{avg} = 2218 Amps**	**1 mS / Div**

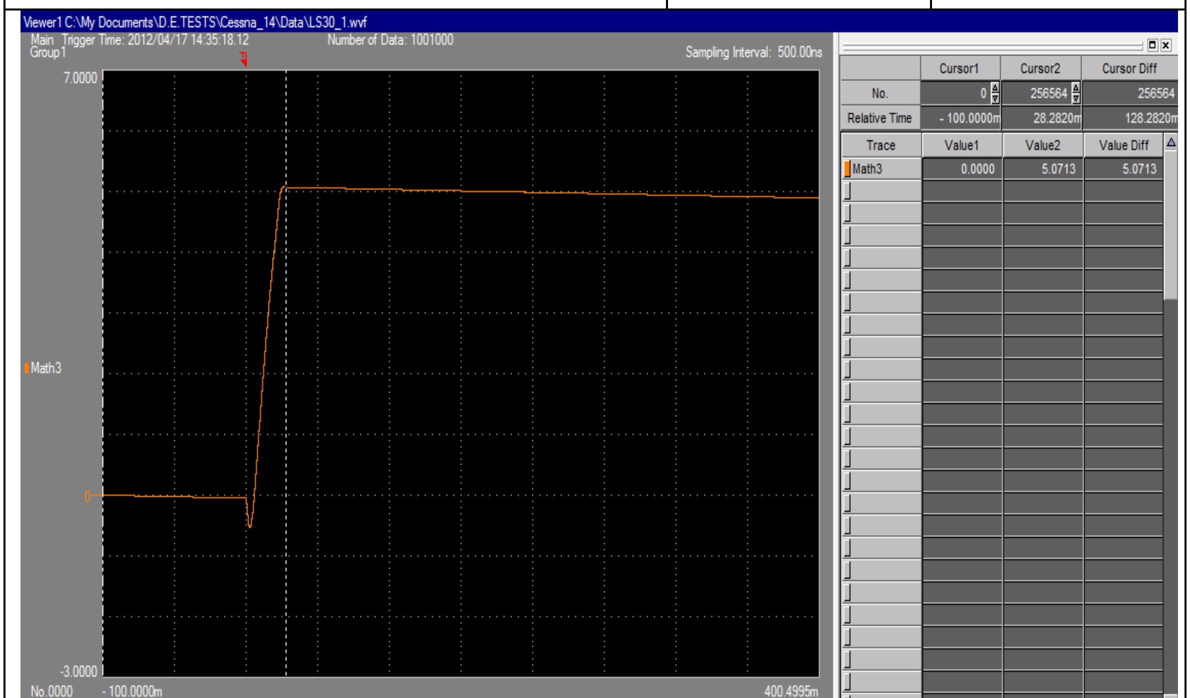


COMPONENT B CHARGE TRANSFER	**11.092 Coulombs**

PANEL: LS-30

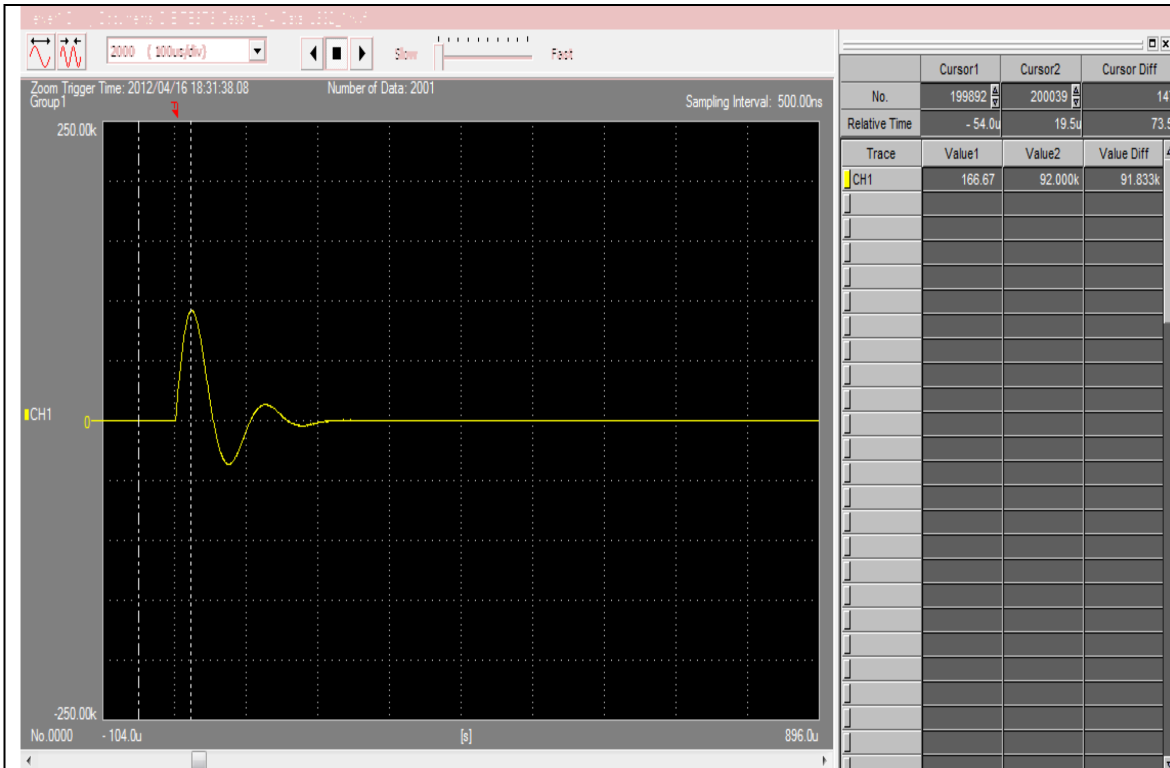


HIGH CURRENT – COMPONENT C*	Ip = 330 Amps	50 mS / Div

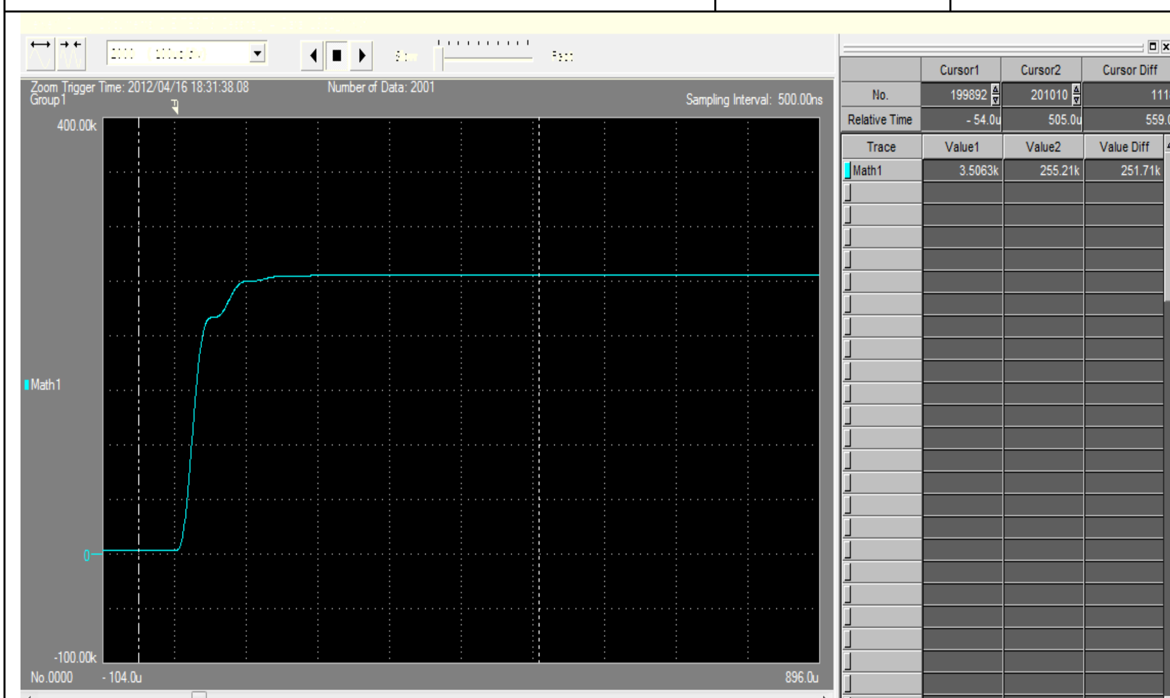


COMPONENT C* CHARGE TRANSFER	5.1 Coulombs

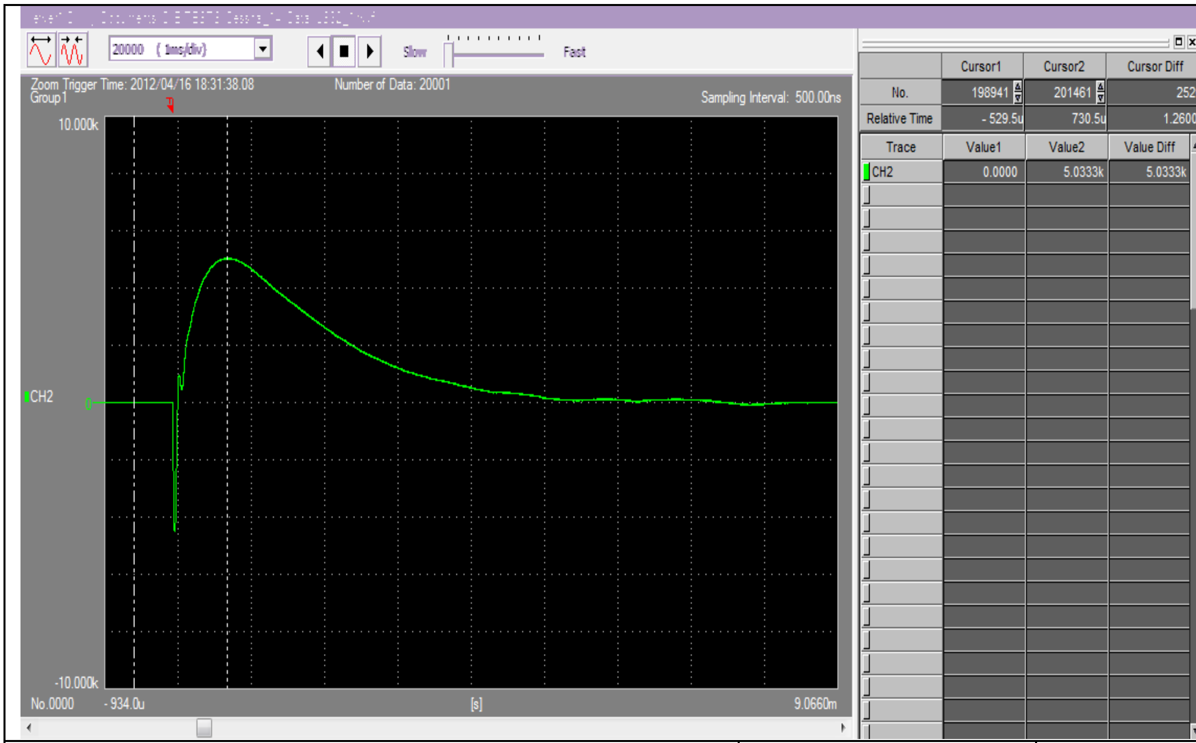
PANEL: LS-30



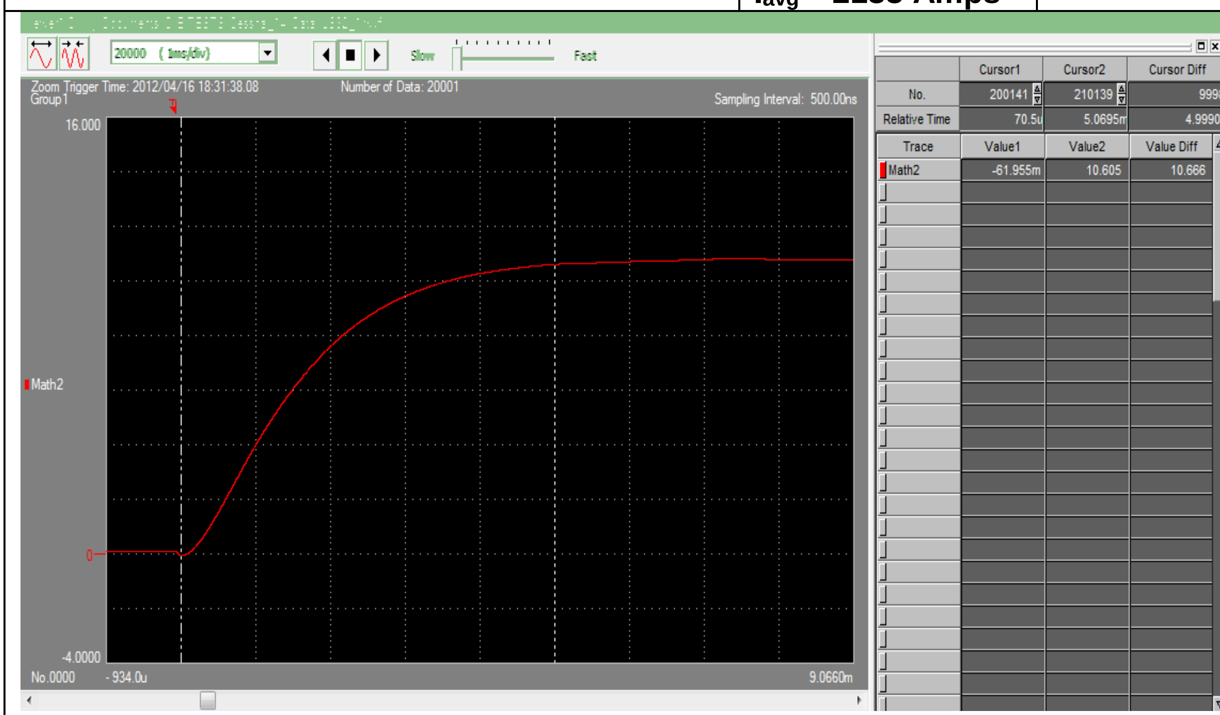
HIGH CURRENT – COMPONENT D	Ip = 91.8 KA	100 uS / Div



COMPONENT D ACTION INTEGRAL	AI = 251710 A^2-S
PANEL: LS-32	

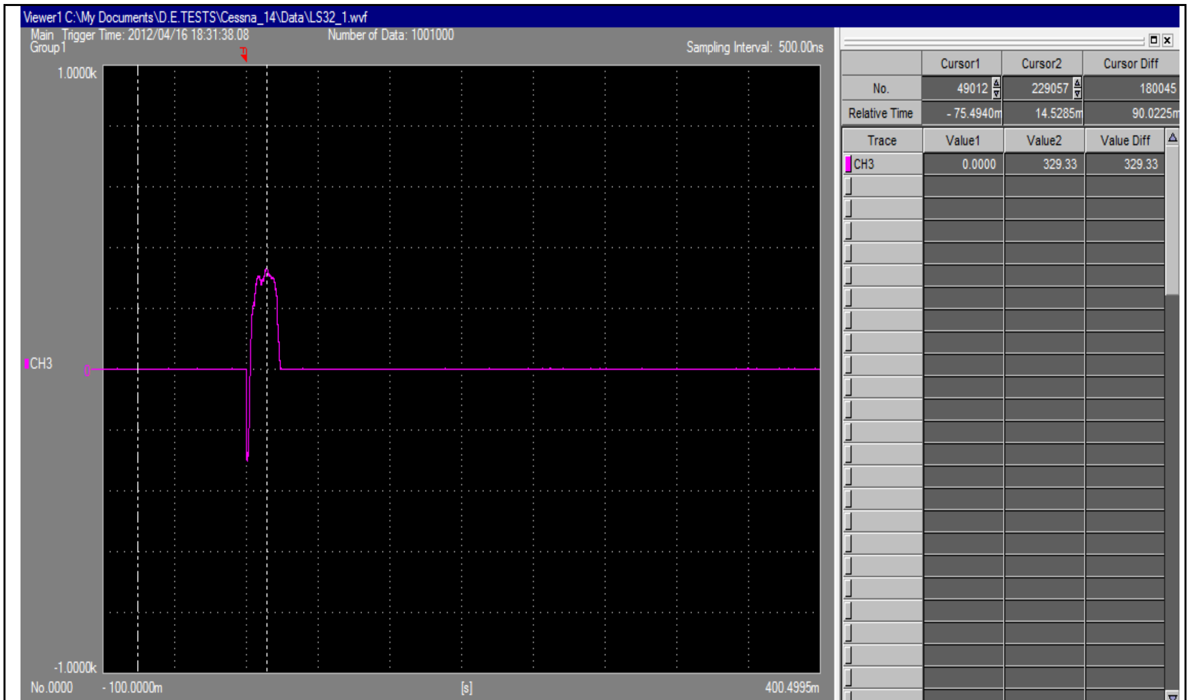


HIGH CURRENT – COMPONENT B	I_P = 5033 Amps I_{avg} = 2133 Amps	1 mS / Div

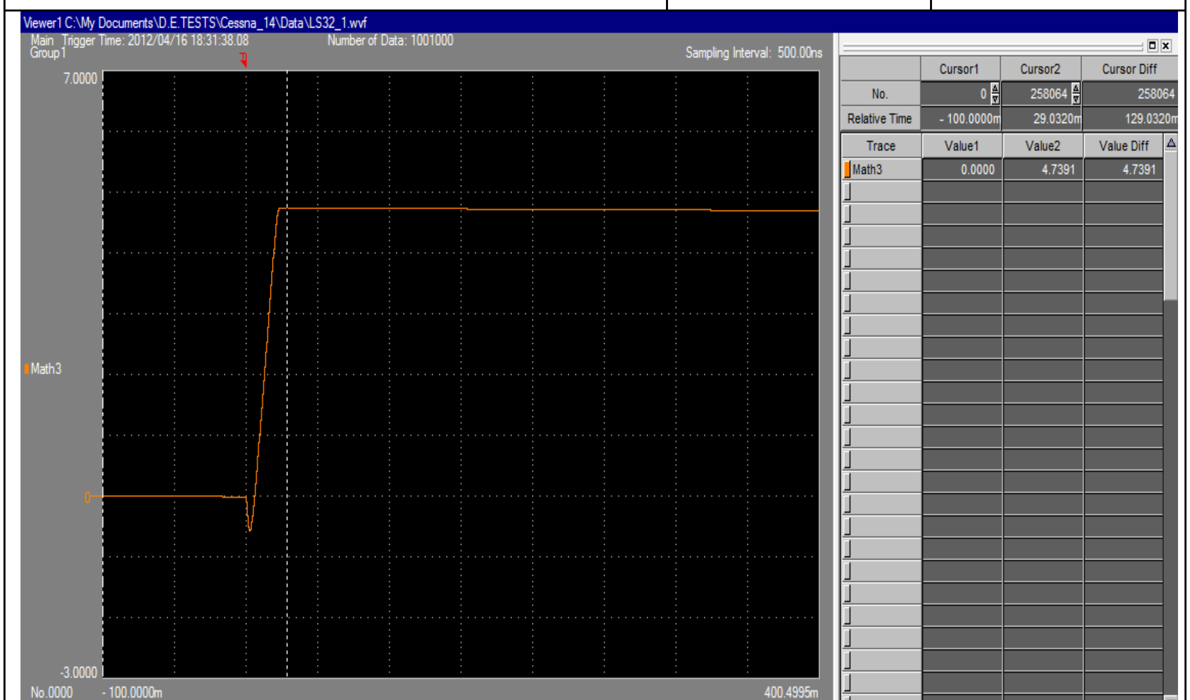


COMPONENT B CHARGE TRANSFER	10.666 Coulombs

PANEL: LS-32

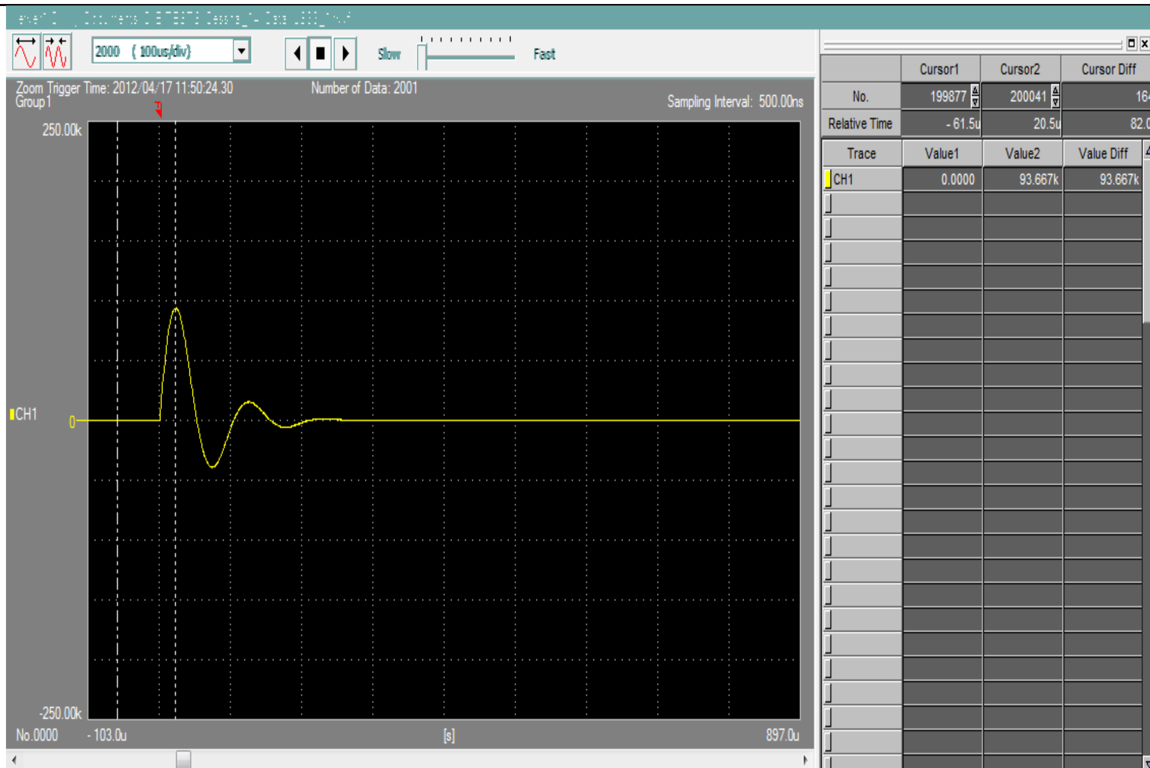


HIGH CURRENT – COMPONENT C*	Ip = 329 Amps	50 mS / Div

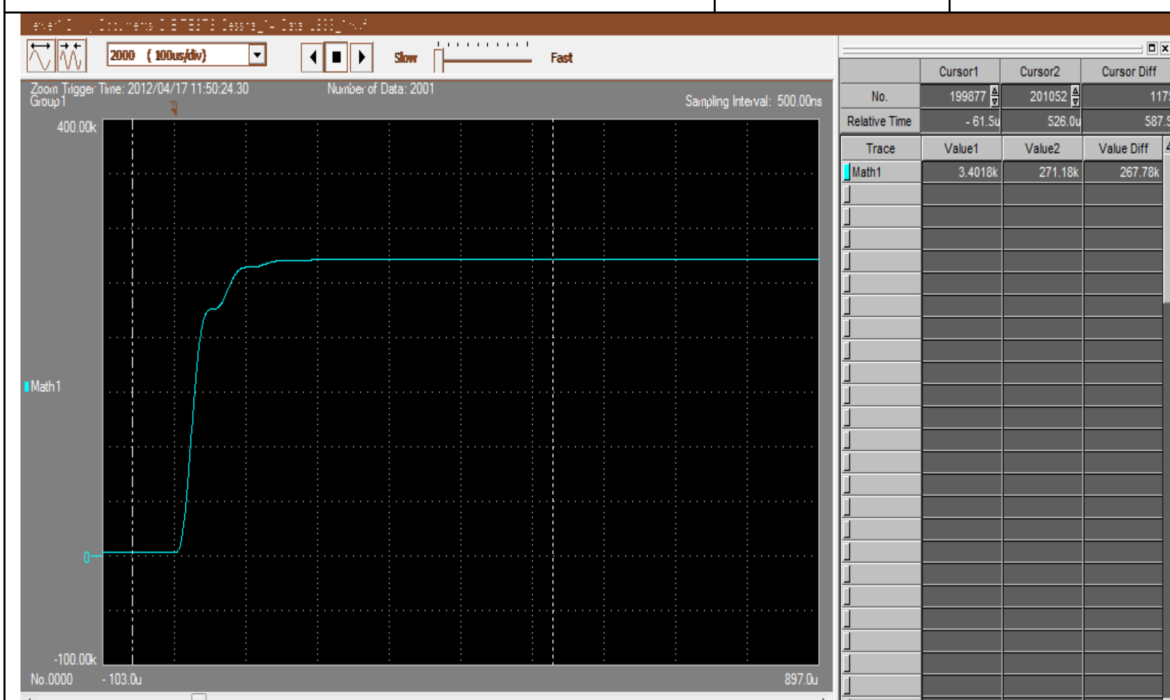


COMPONENT C* CHARGE TRANSFER	4.7 Coulombs

PANEL: LS-32

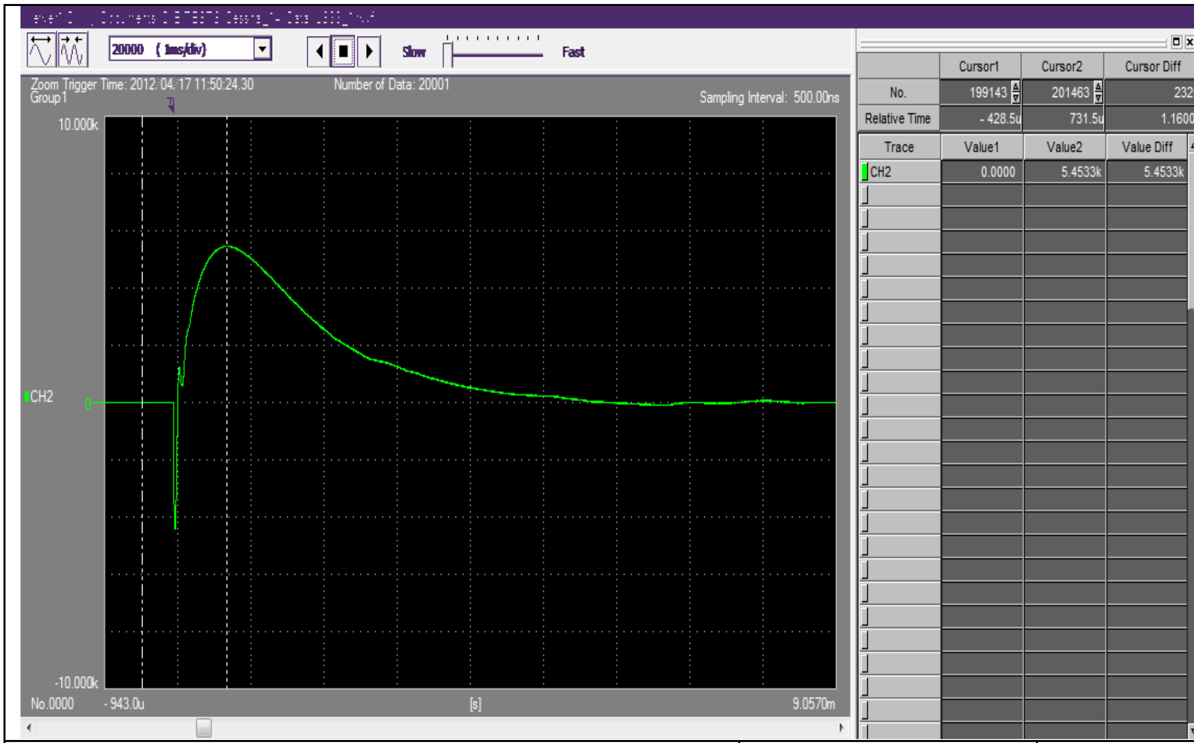


HIGH CURRENT – COMPONENT D	Ip = 93.7 KA	100 uS / Div

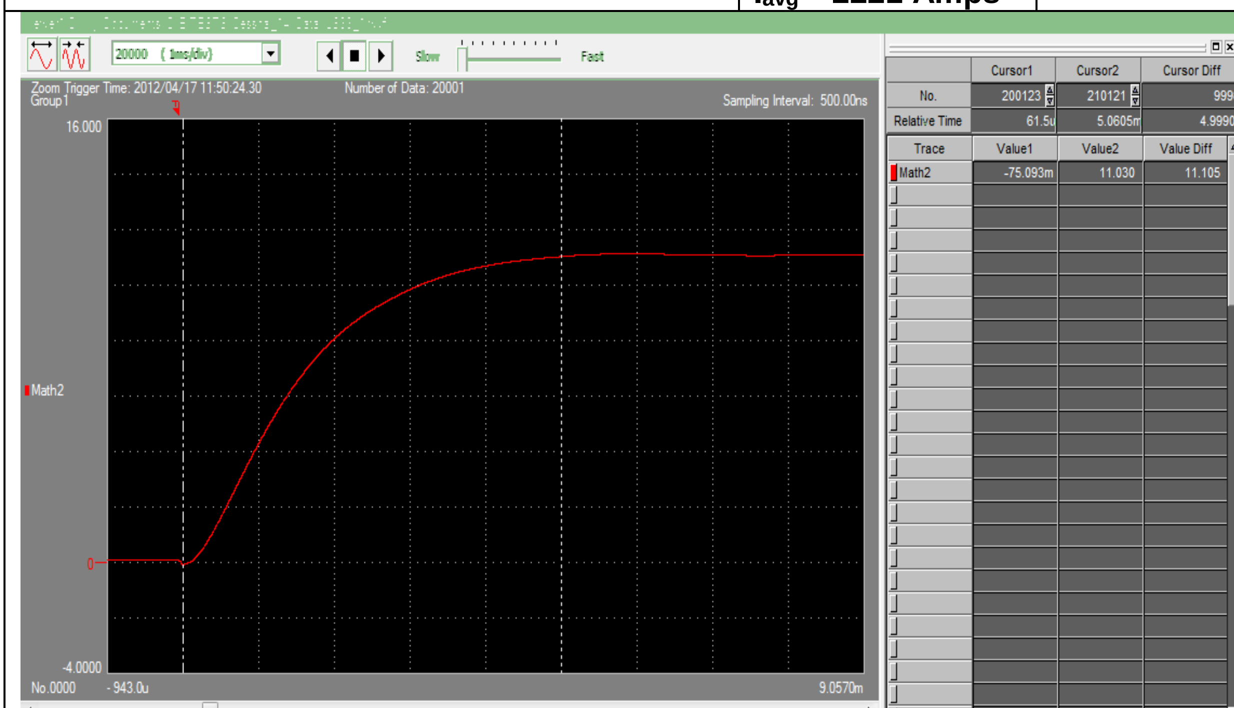


COMPONENT D ACTION INTEGRAL	AI = 267780 A^2-S

PANEL: LS-33

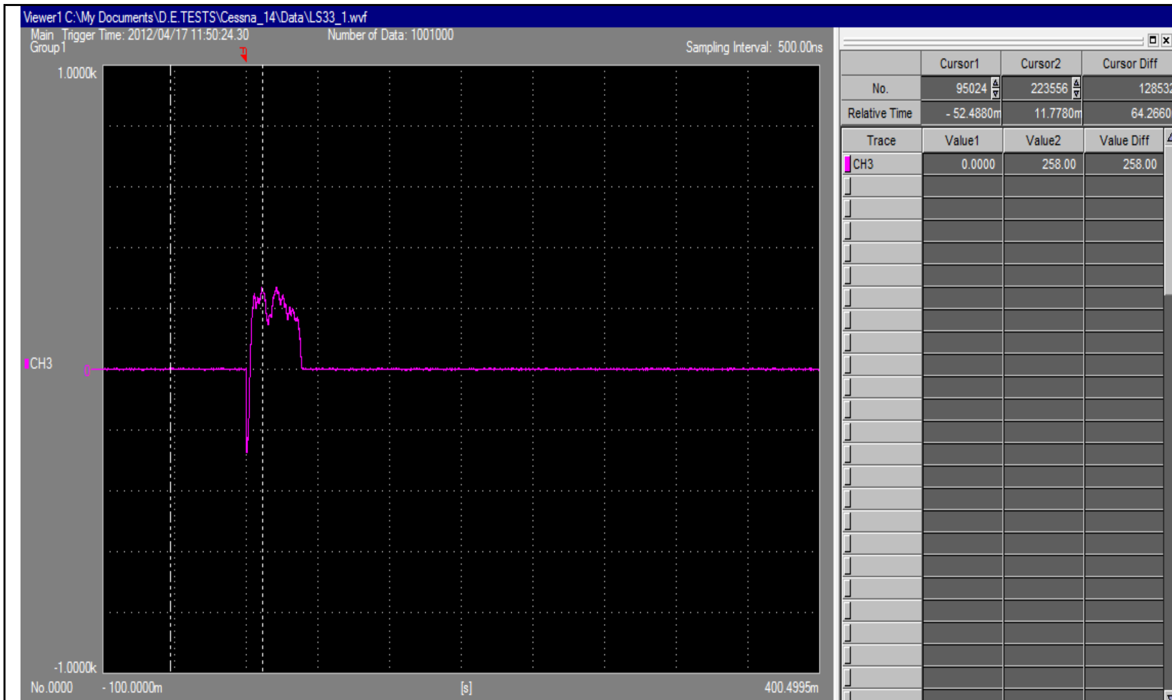


HIGH CURRENT – COMPONENT B	I_P = 5453 Amps I_{avg} = 2221 Amps	1 mS / Div

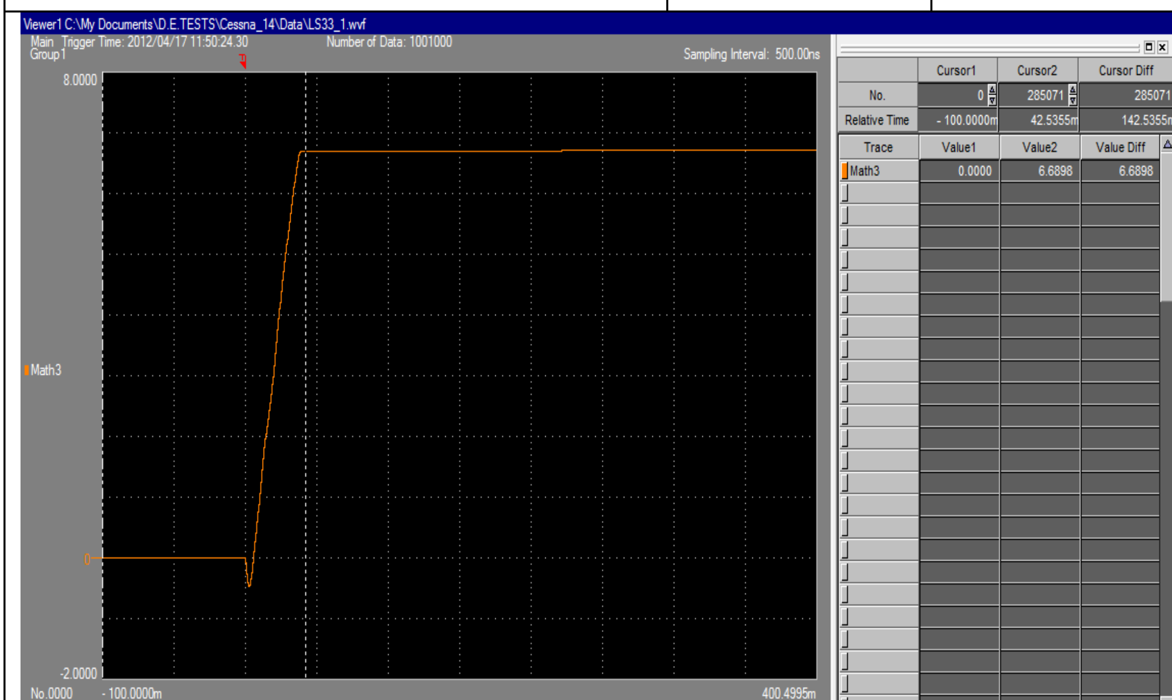


COMPONENT B CHARGE TRANSFER	11.105 Coulombs

PANEL: LS-33

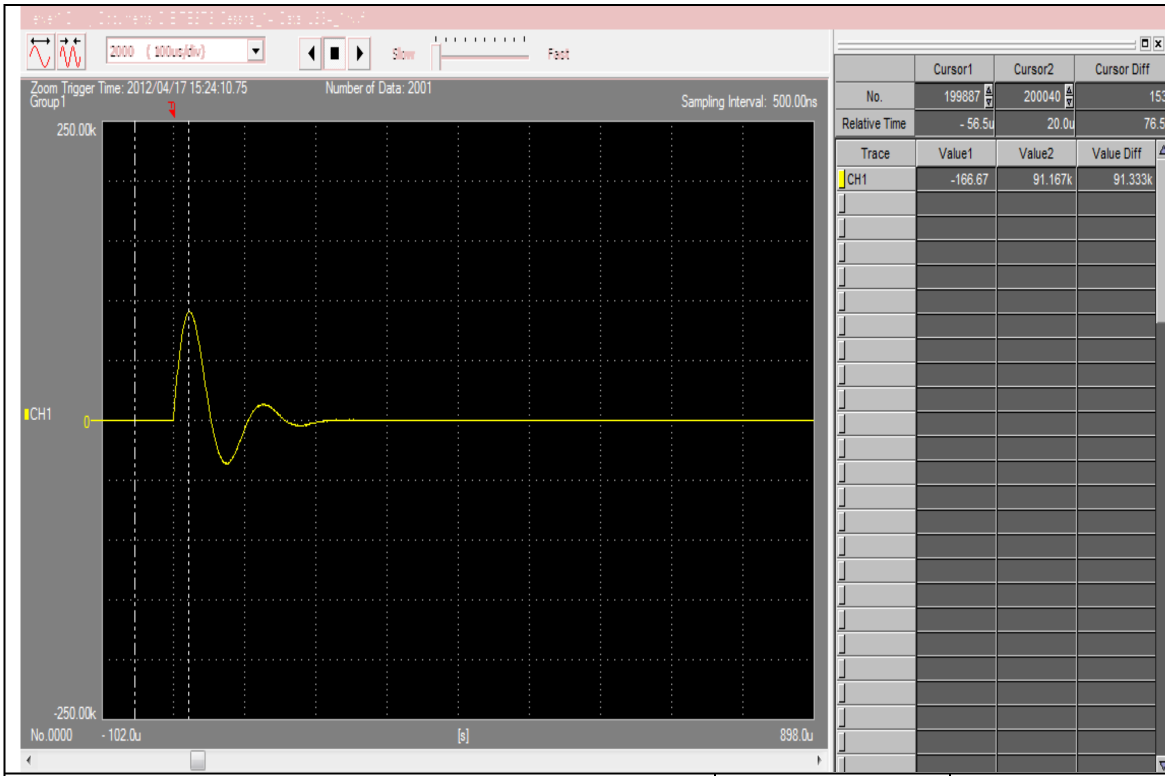


HIGH CURRENT – COMPONENT C*	Ip = 258 Amps	50 mS / Div

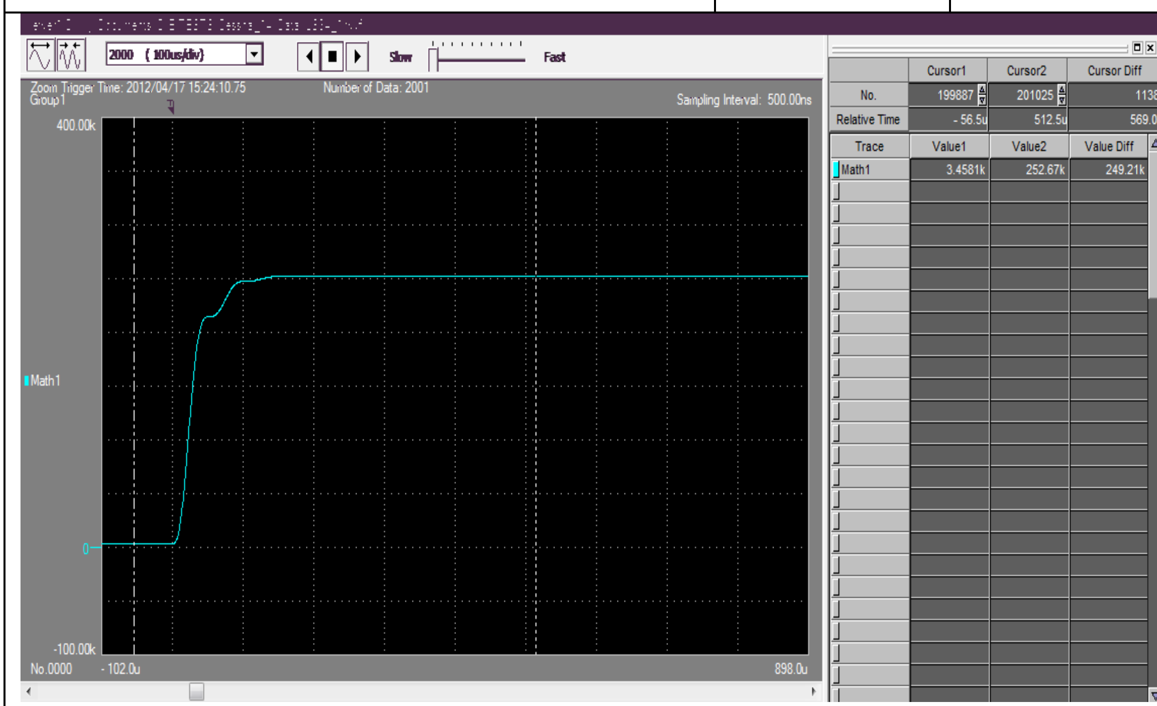


COMPONENT C* CHARGE TRANSFER	6.7 Coulombs

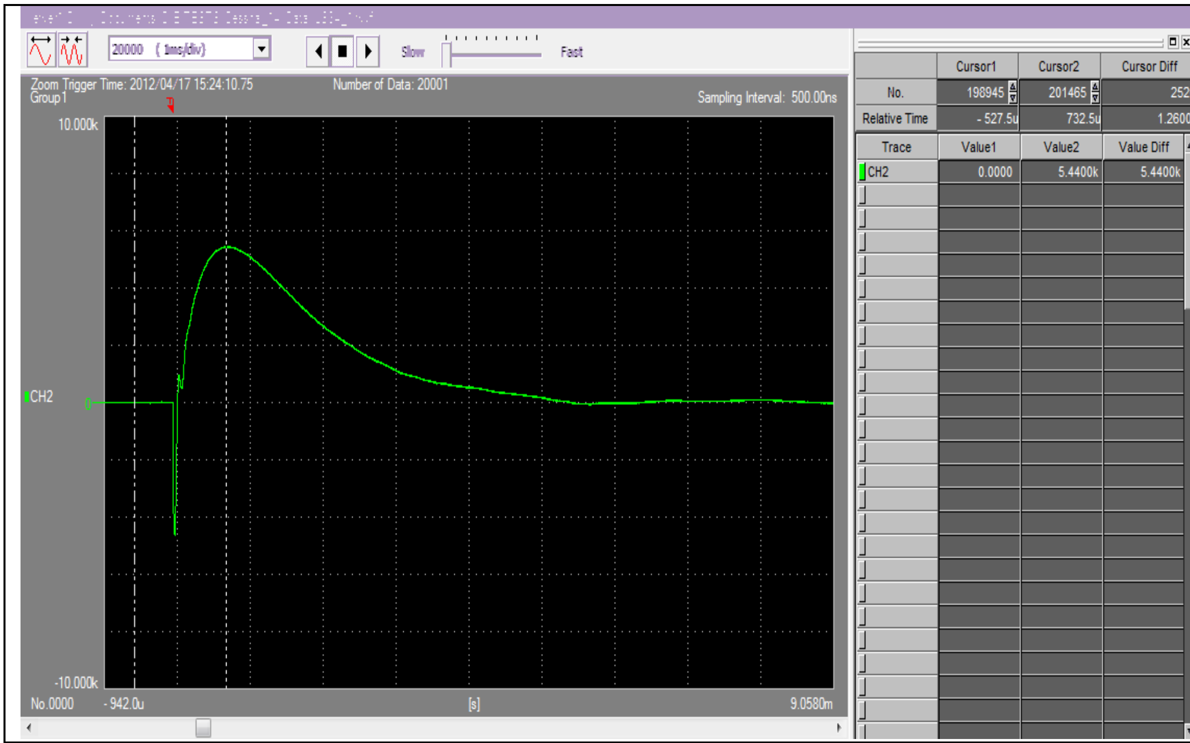
PANEL: LS-33



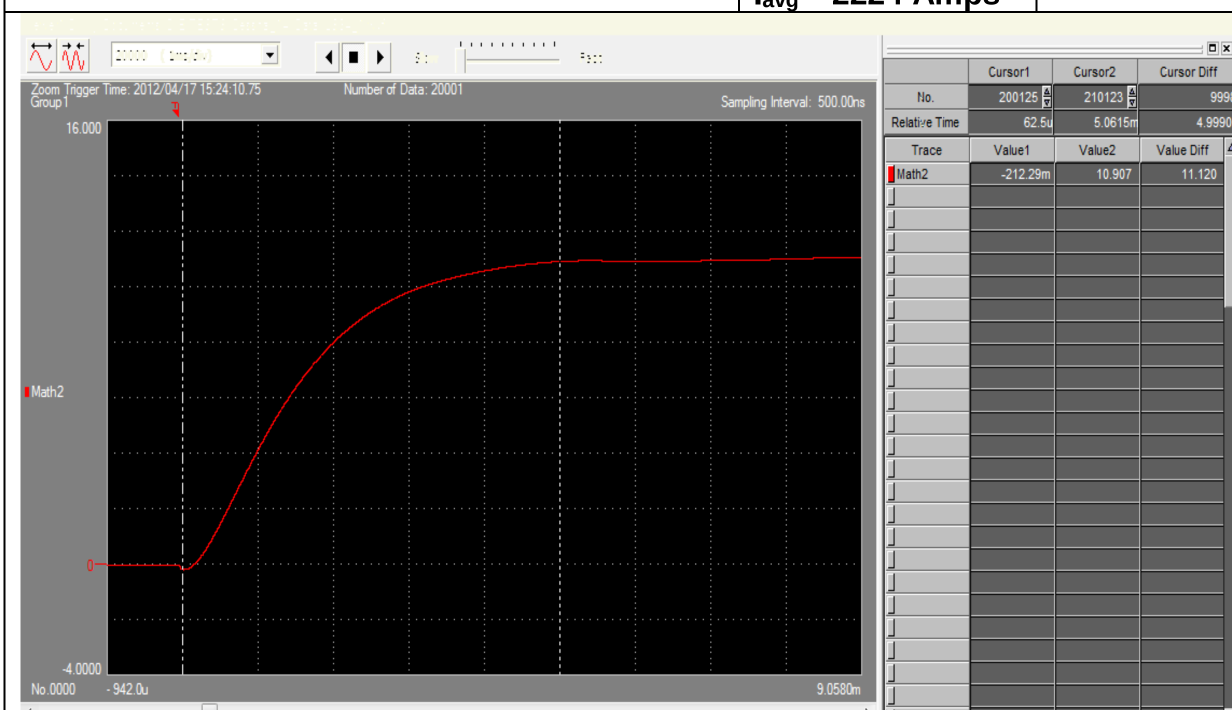
HIGH CURRENT – COMPONENT D	**Ip = 91.3 KA**	**100 uS / Div**



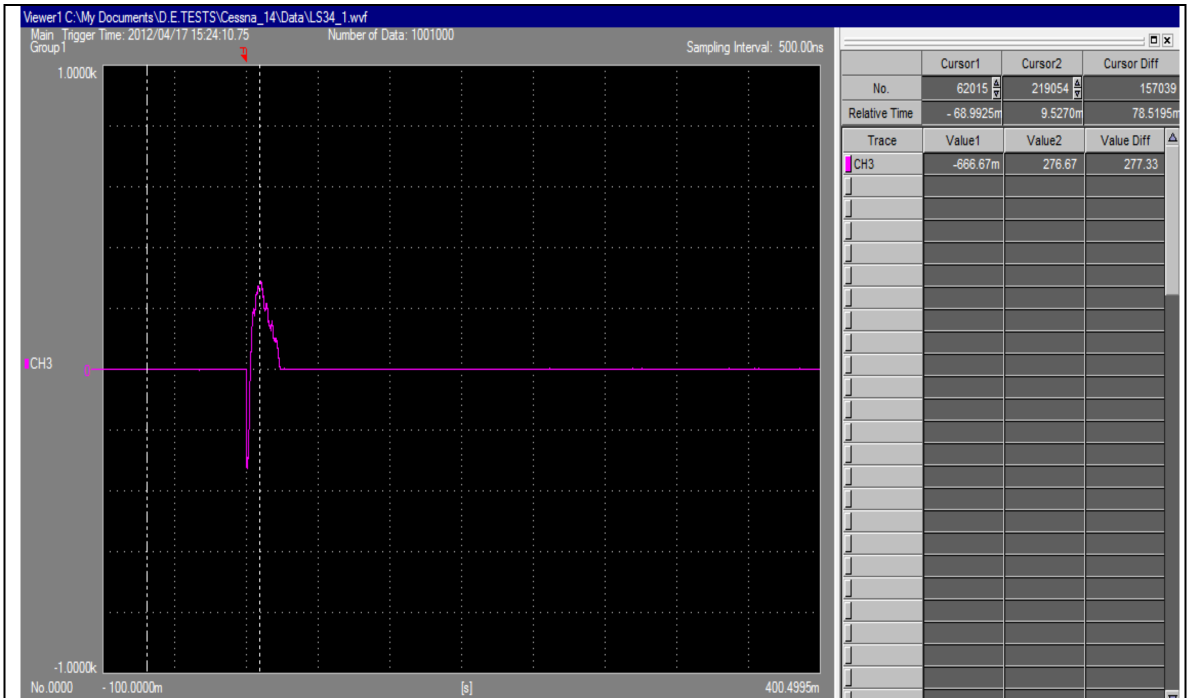
COMPONENT D ACTION INTEGRAL	**AI = 249210 A^2-S**
PANEL: LS-34	



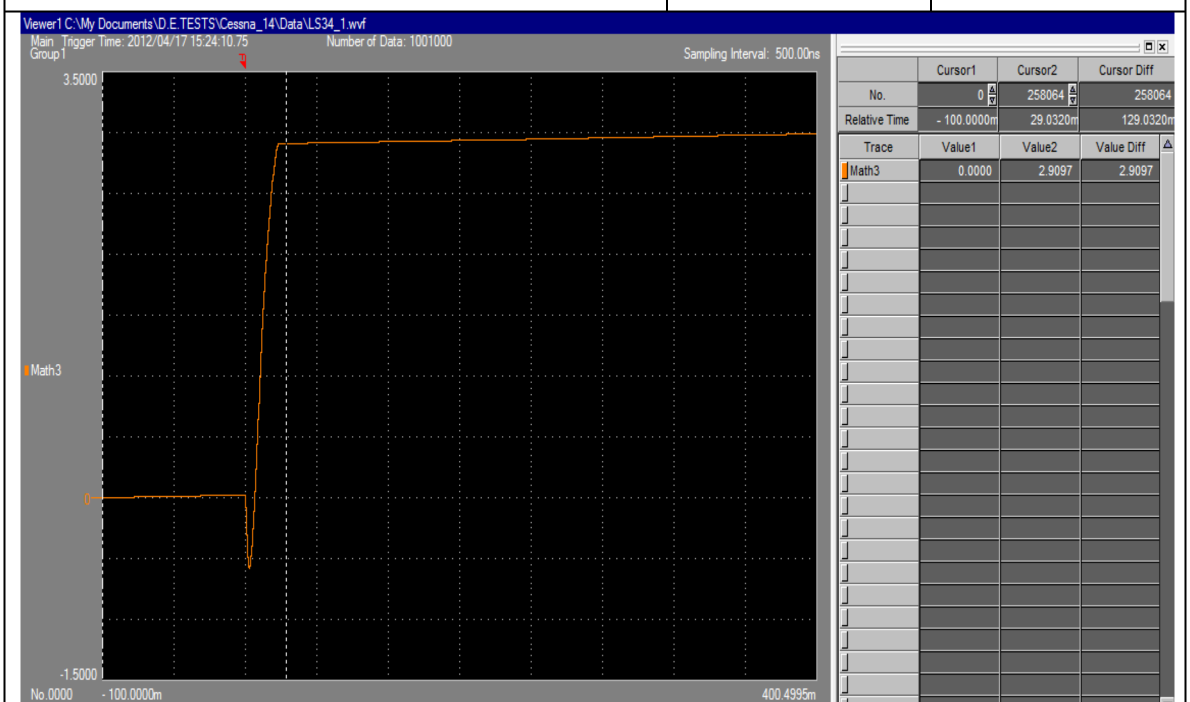
HIGH CURRENT – COMPONENT B	I_P = 5440 Amps I_{avg} = 2224 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.120 Coulombs
PANEL: LS-34	

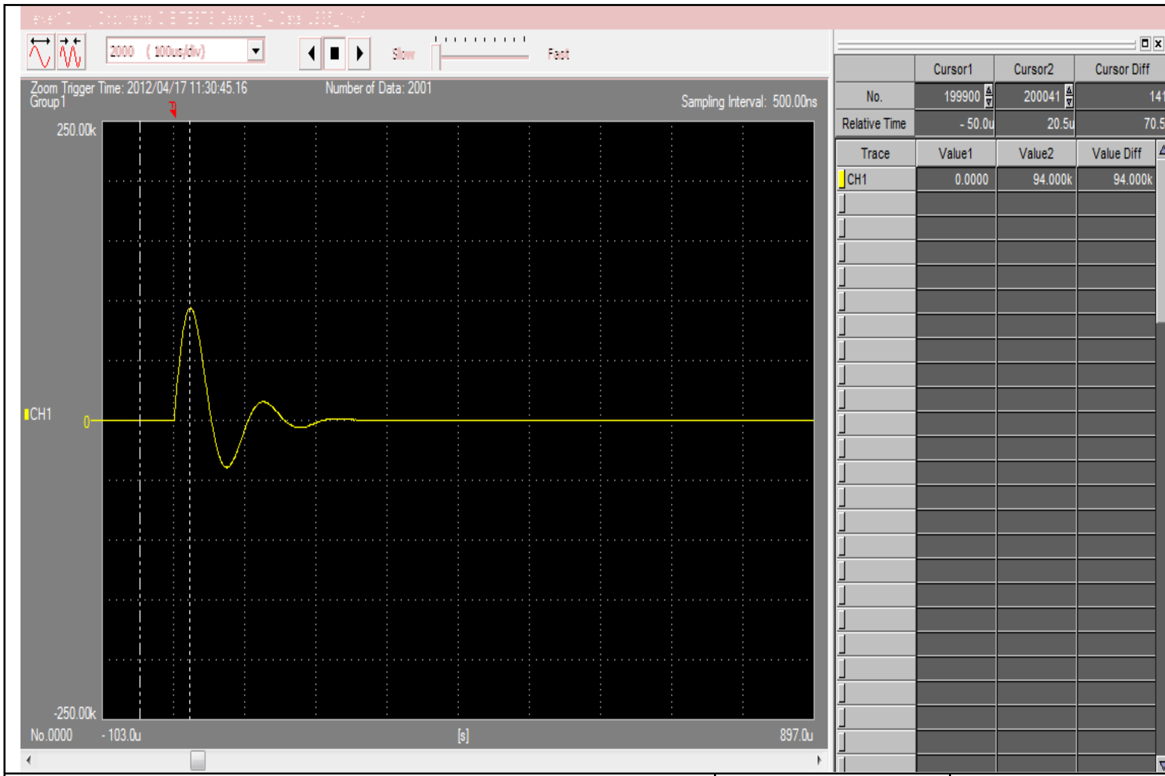


HIGH CURRENT – COMPONENT C*	Ip = 277Amps	50 mS / Div

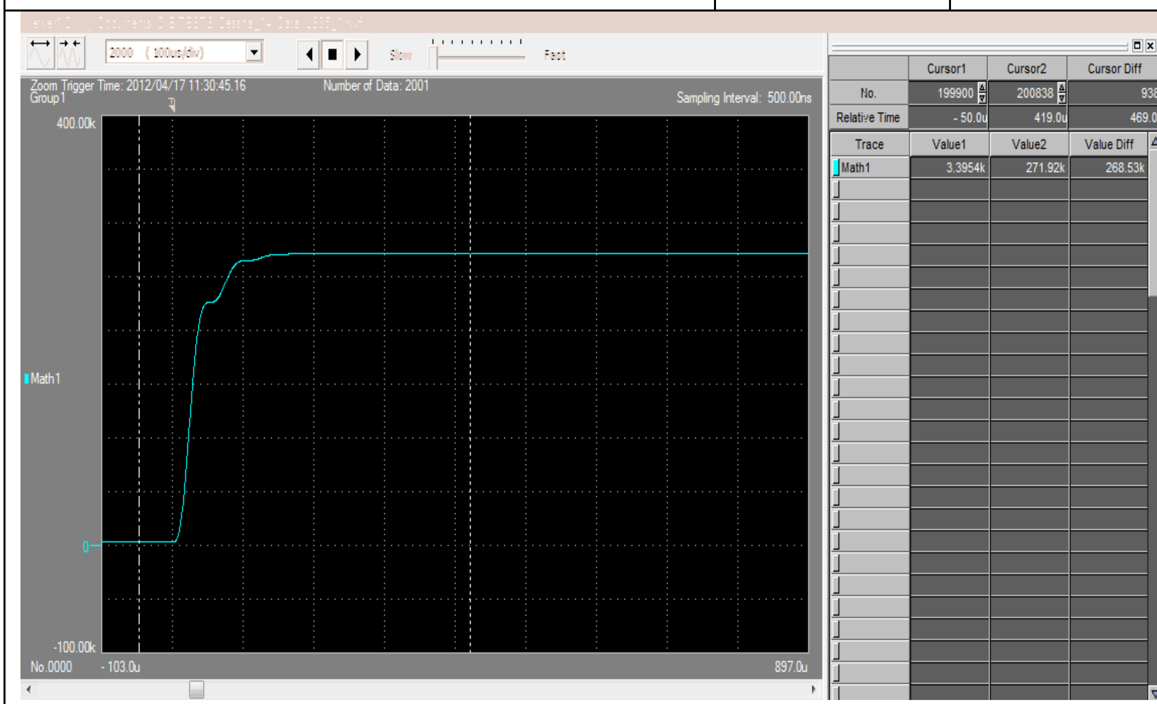


COMPONENT C* CHARGE TRANSFER	2.9 Coulombs

PANEL: LS-34

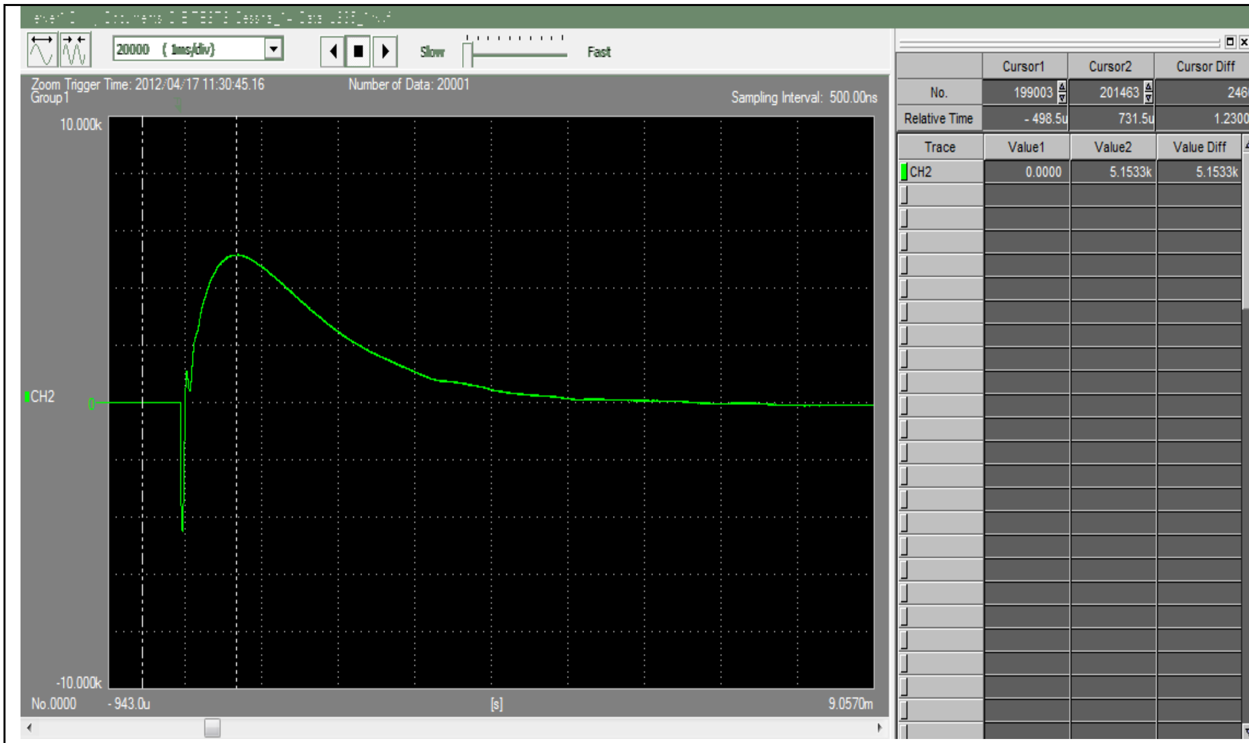


HIGH CURRENT – COMPONENT D	Ip = 94.0 KA	100 uS / Div

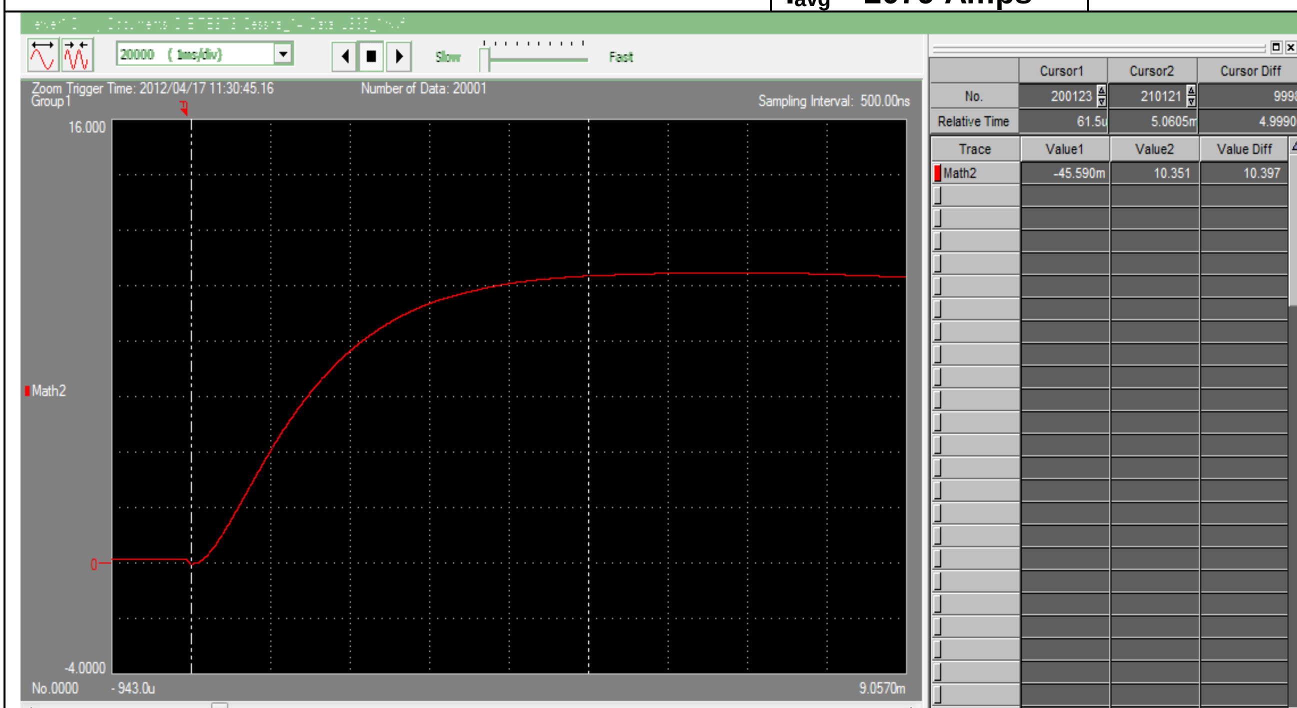


COMPONENT D ACTION INTEGRAL	AI = 268530 A^2-S

PANEL: LS-35

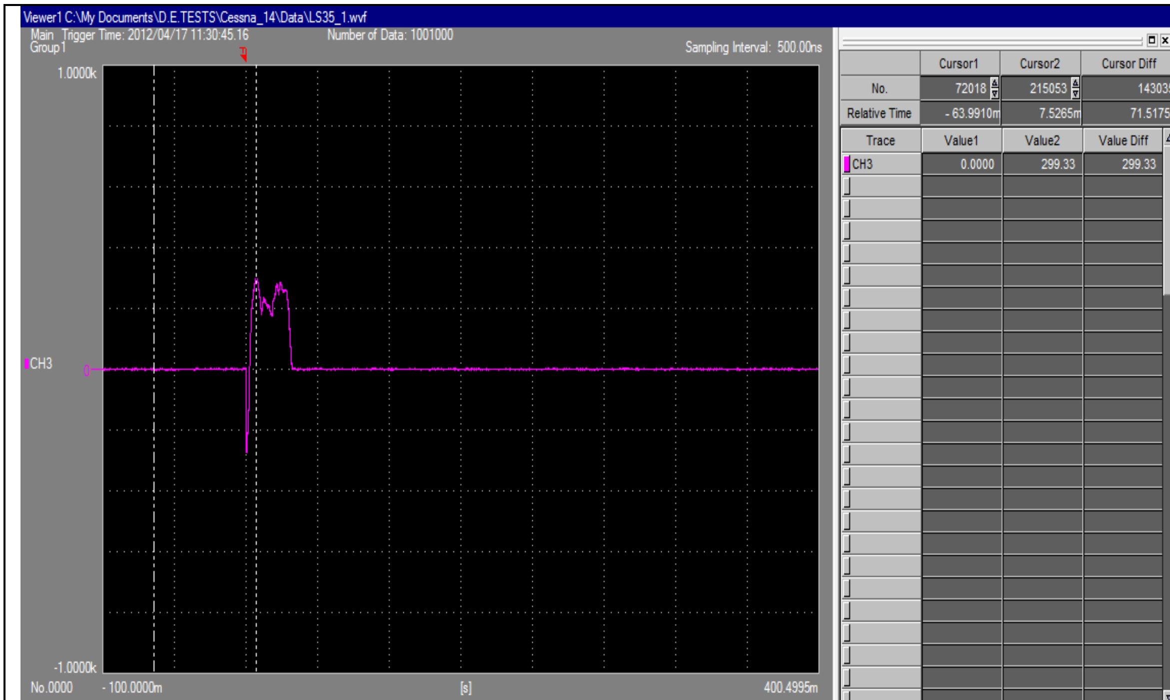


HIGH CURRENT – COMPONENT B	I_P = 5153 Amps I_{avg} = 2079 Amps	1 mS / Div

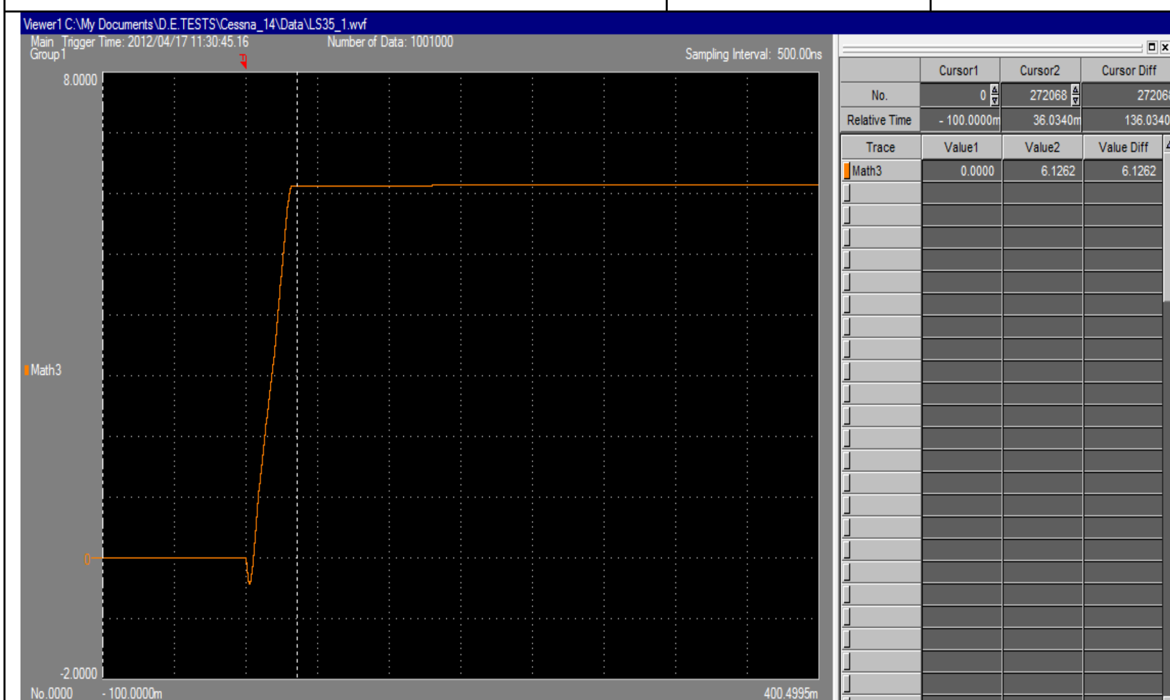


COMPONENT B CHARGE TRANSFER	10.397 Coulombs

PANEL: LS-35

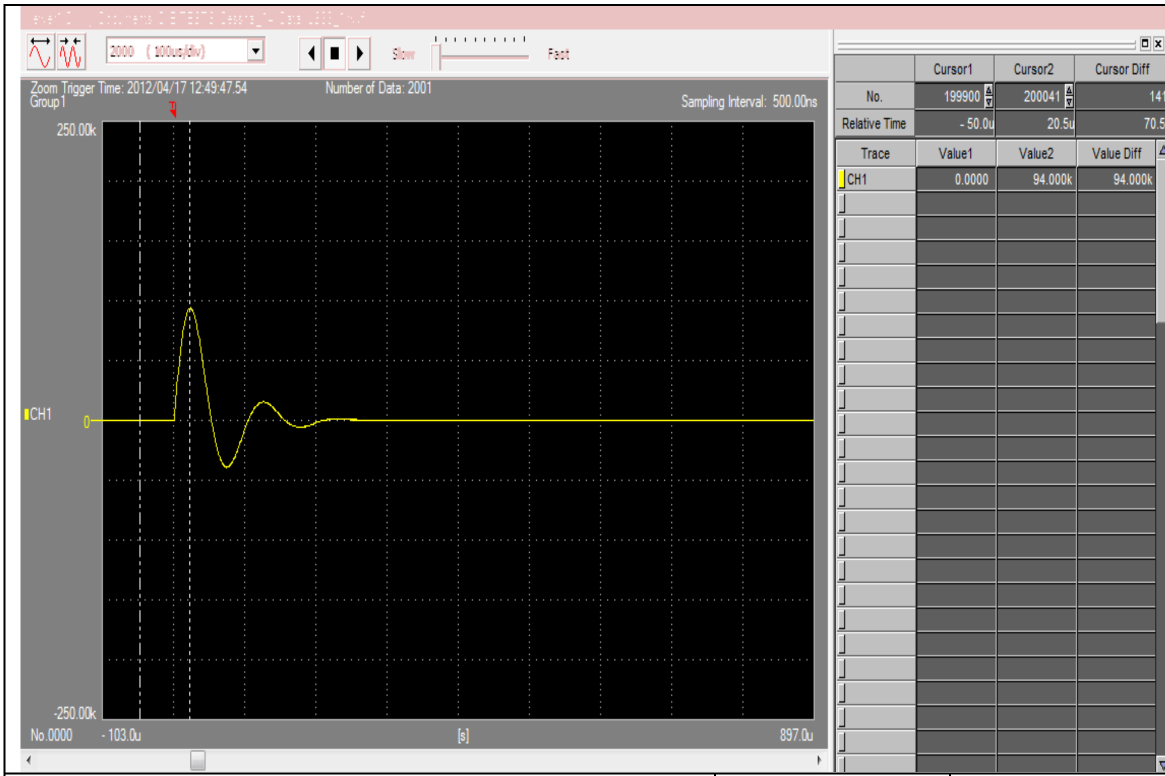


HIGH CURRENT – COMPONENT C*	Ip = 299 Amps	50 mS / Div

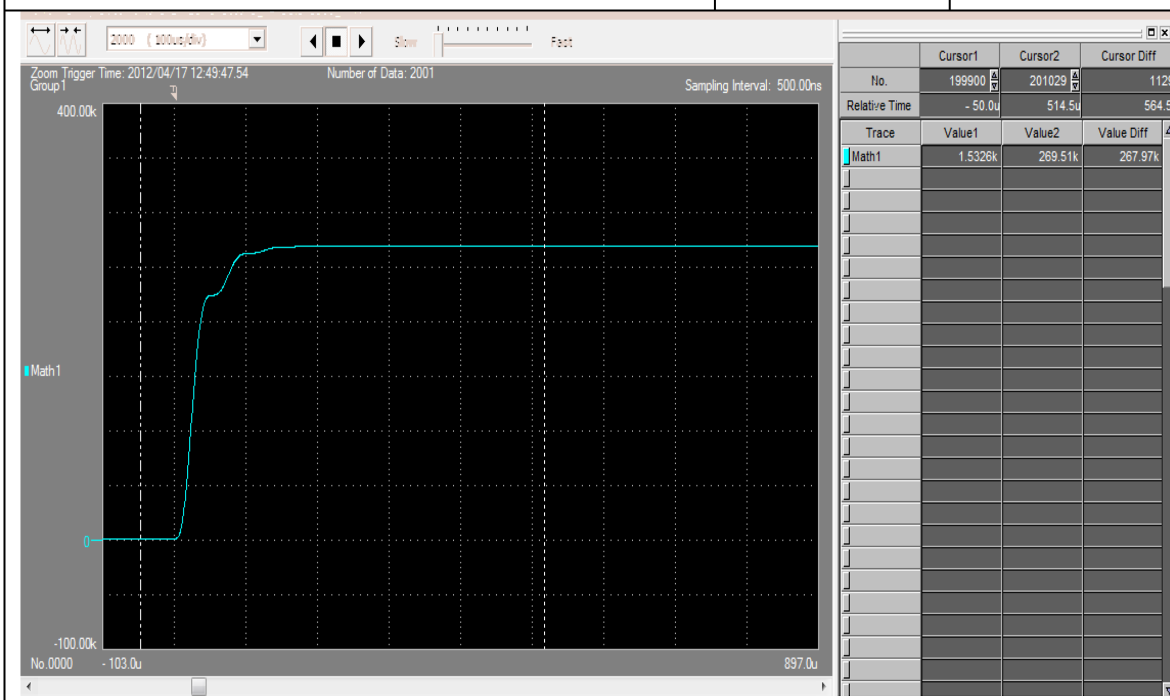


COMPONENT C* CHARGE TRANSFER	6.1 Coulombs

PANEL: LS-35

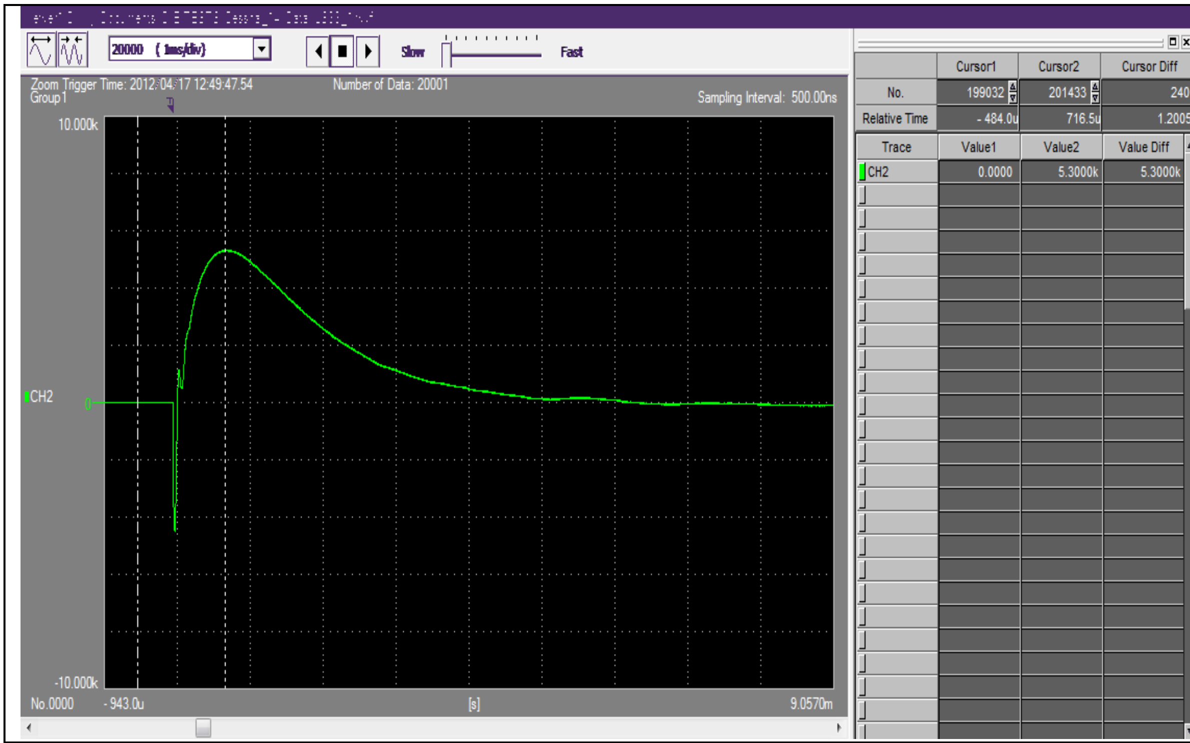


HIGH CURRENT – COMPONENT D	Ip = 94.0 KA	100 uS / Div

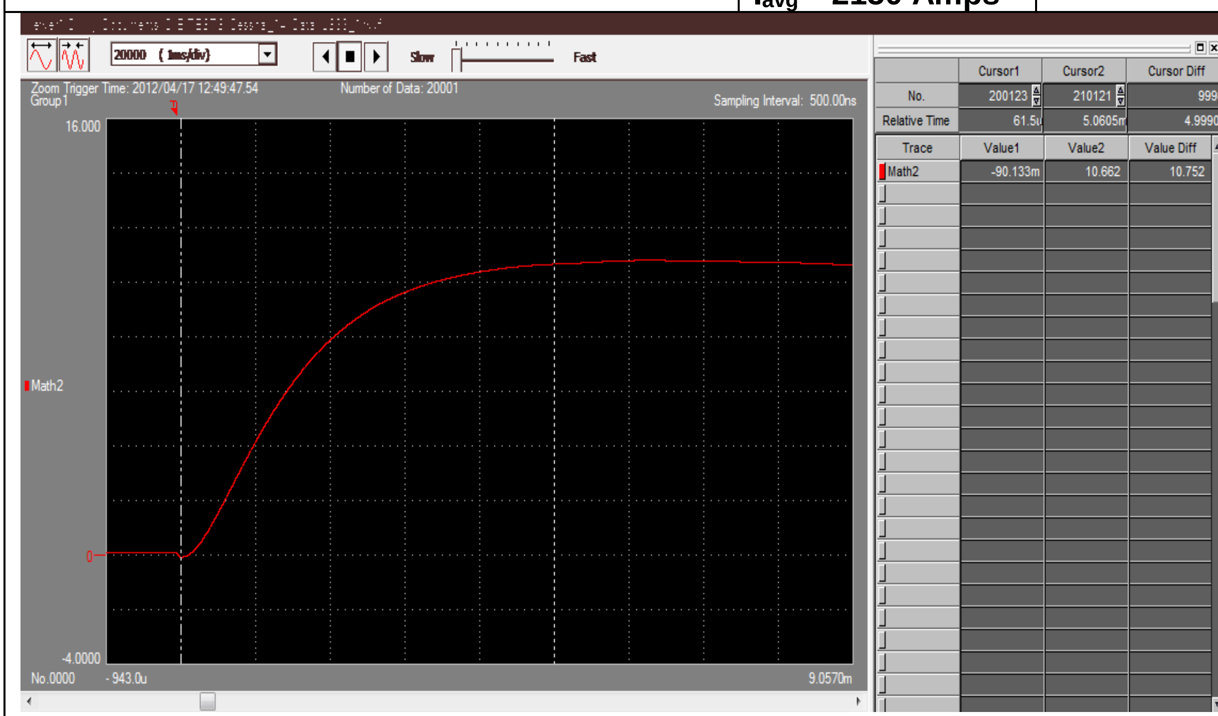


COMPONENT D ACTION INTEGRAL	AI = 267970 A^2-S

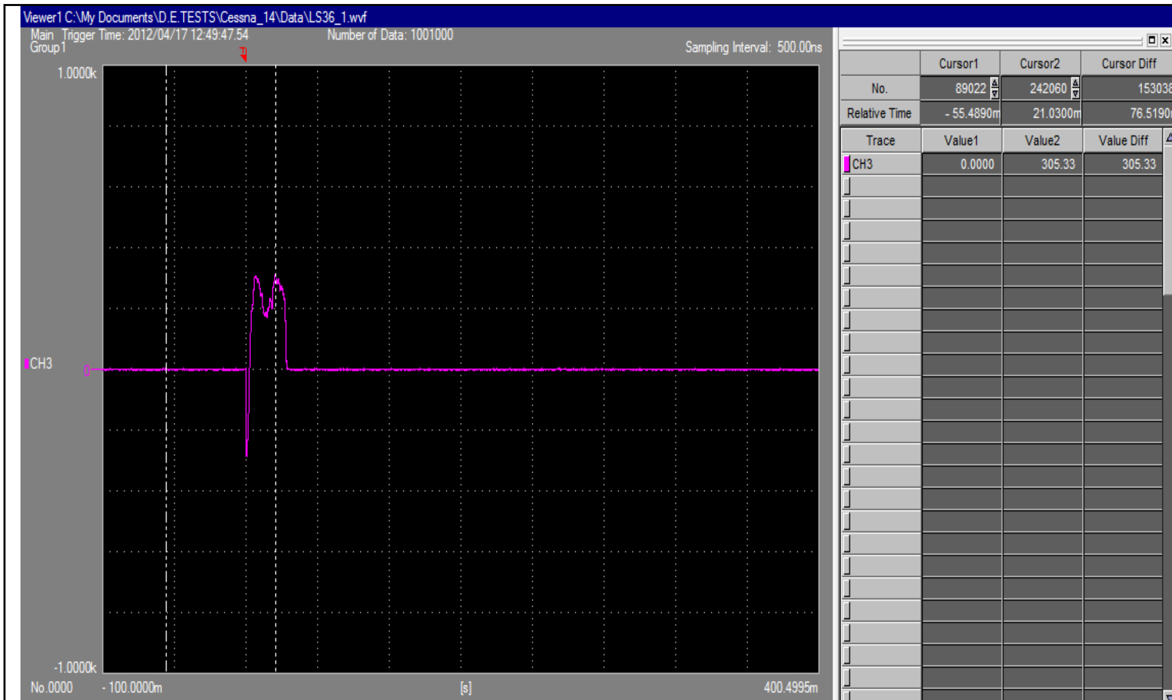
PANEL: LS-36



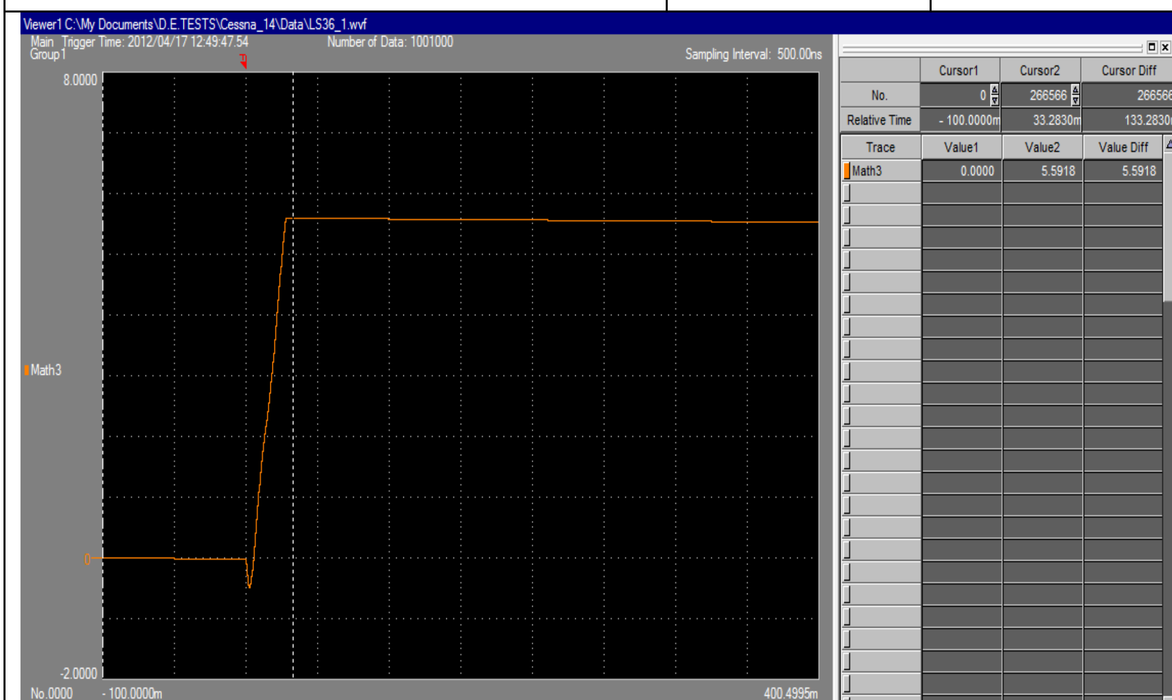
HIGH CURRENT – COMPONENT B	**I_P = 5300 Amps** **I_{avg} = 2150 Amps**	**1 mS / Div**



COMPONENT B CHARGE TRANSFER	**10.752 Coulombs**
PANEL: LS-36	

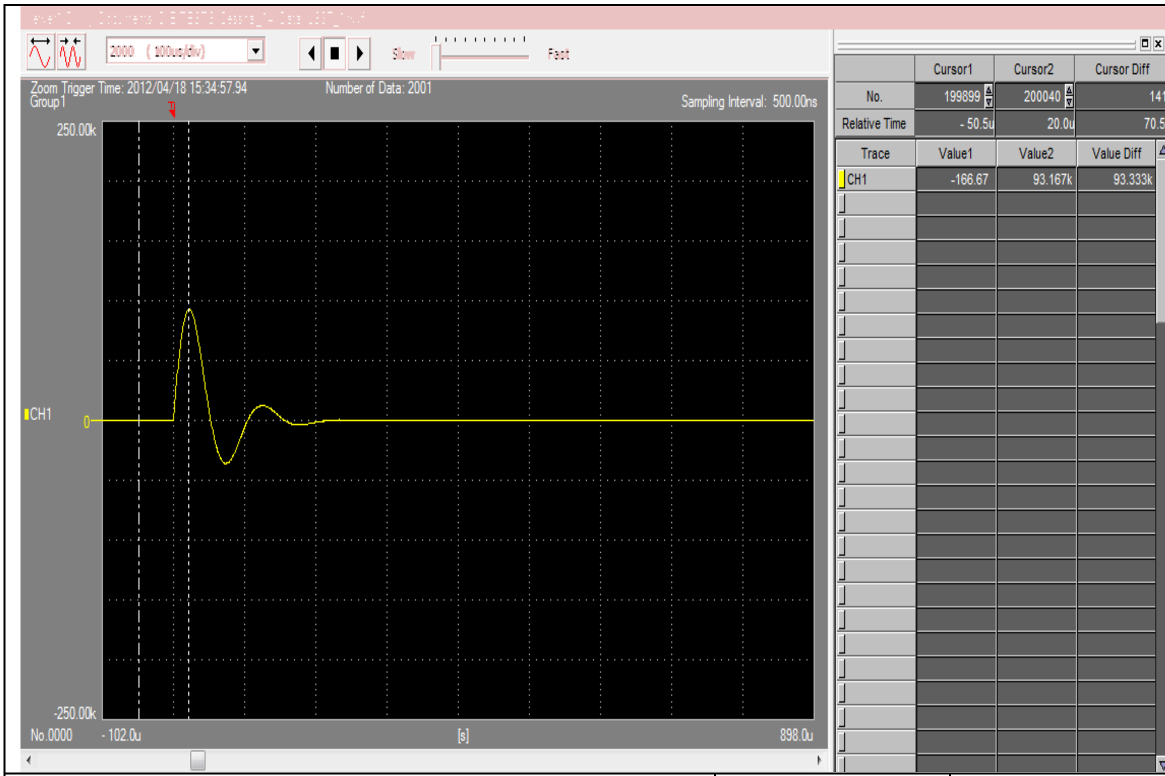


HIGH CURRENT – COMPONENT C*	Ip = 305 Amps	50 mS / Div

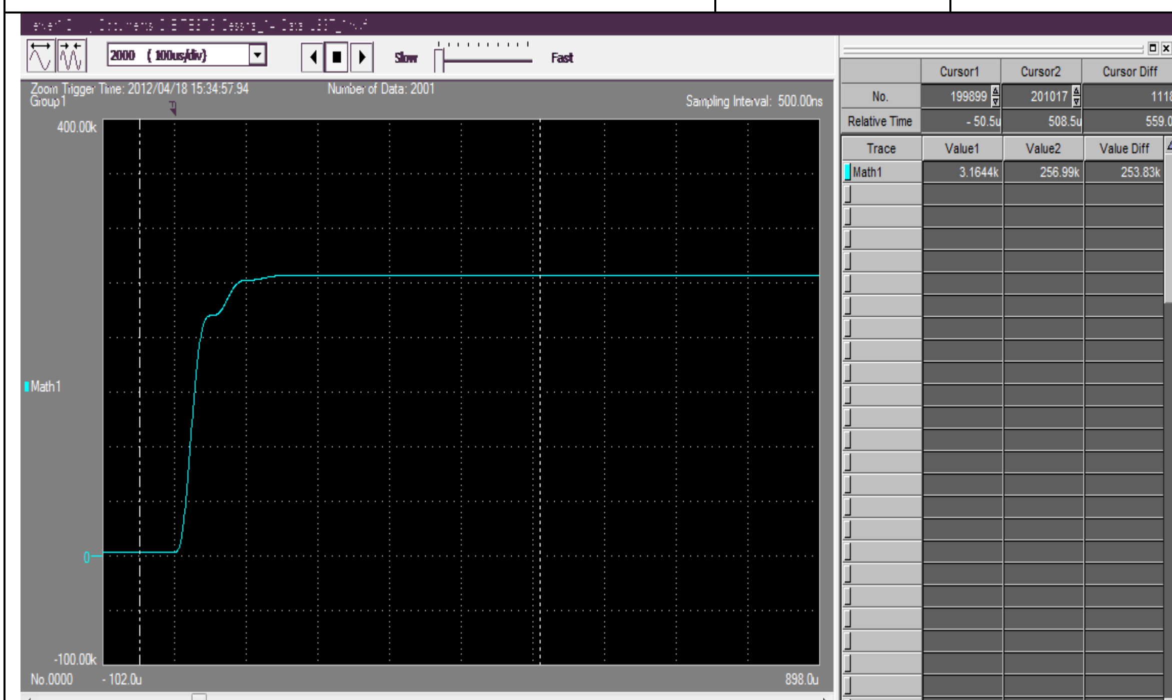


COMPONENT C* CHARGE TRANSFER	5.6 Coulombs

PANEL: LS-36

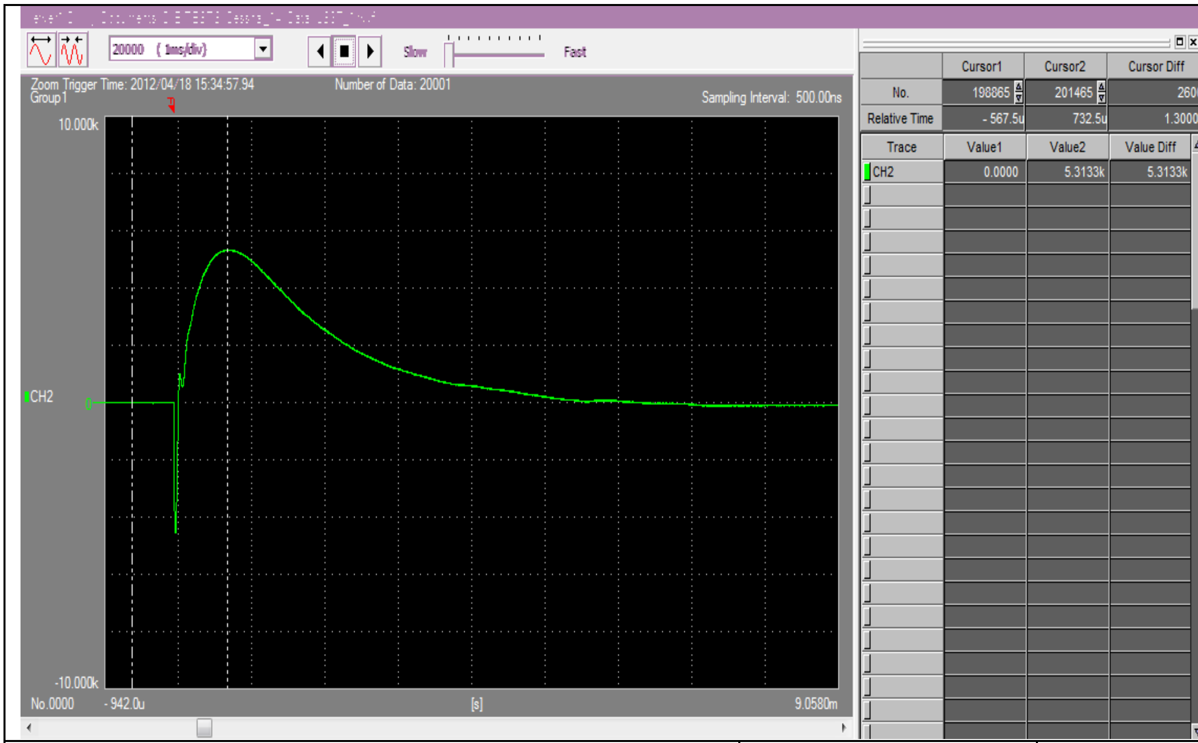


HIGH CURRENT – COMPONENT D	Ip = 93.3 KA	100 uS / Div

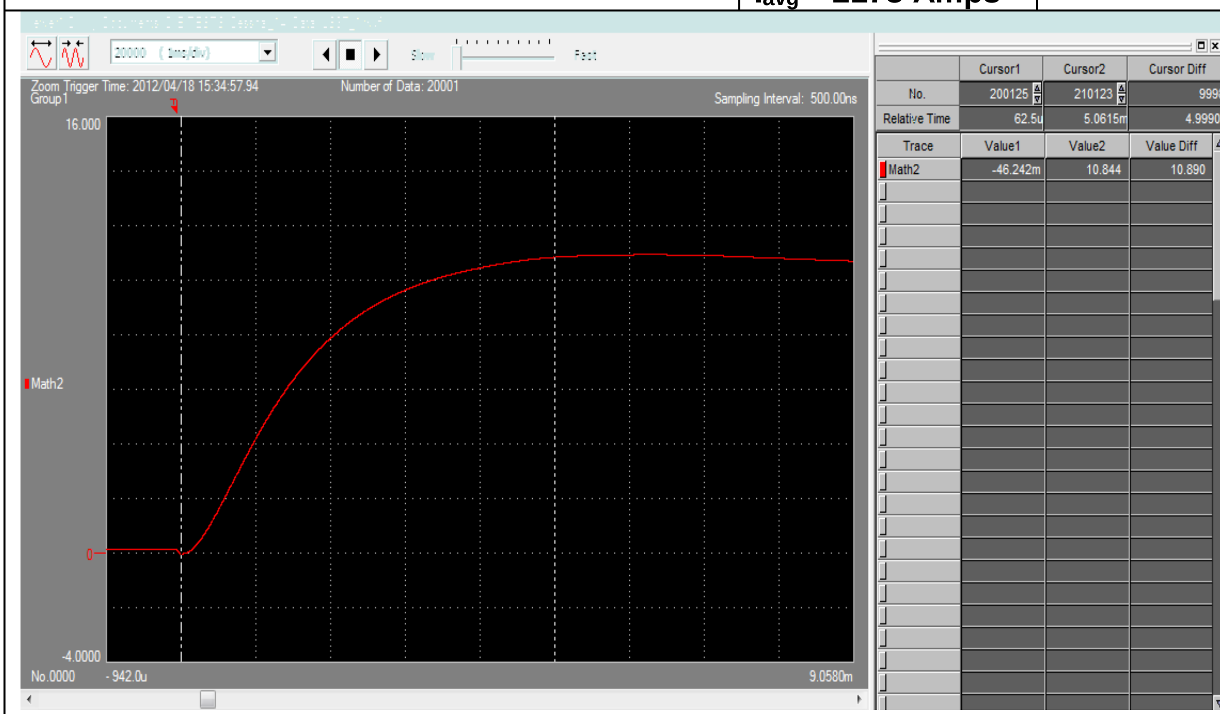


COMPONENT D ACTION INTEGRAL	AI = 253830 A^2-S

PANEL: LS-37

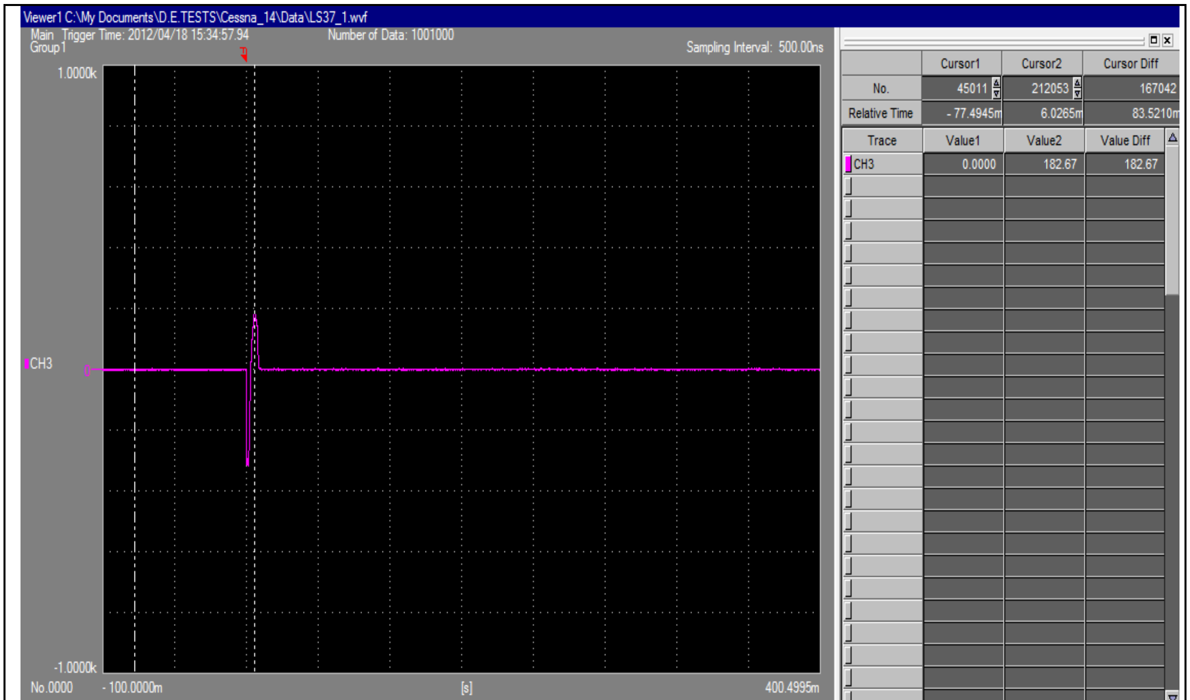


HIGH CURRENT – COMPONENT B	I_P = 5313 Amps I_{avg} = 2178 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.890 Coulombs

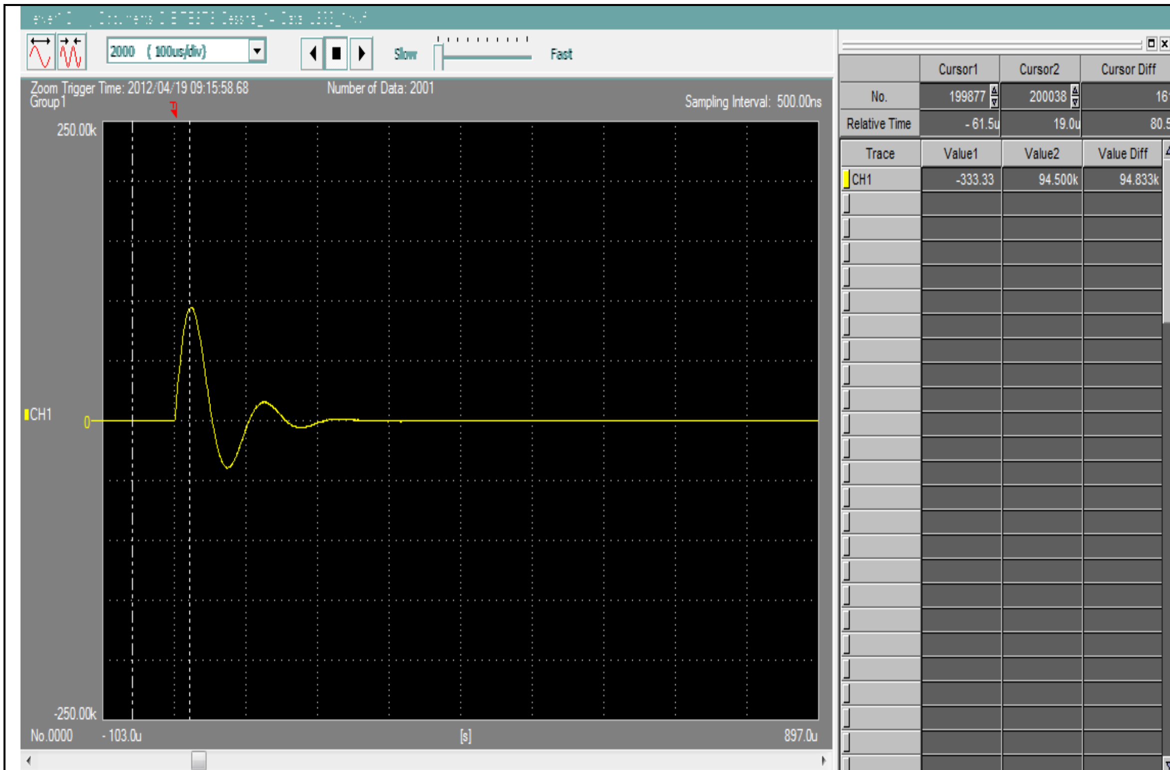
PANEL: LS-37



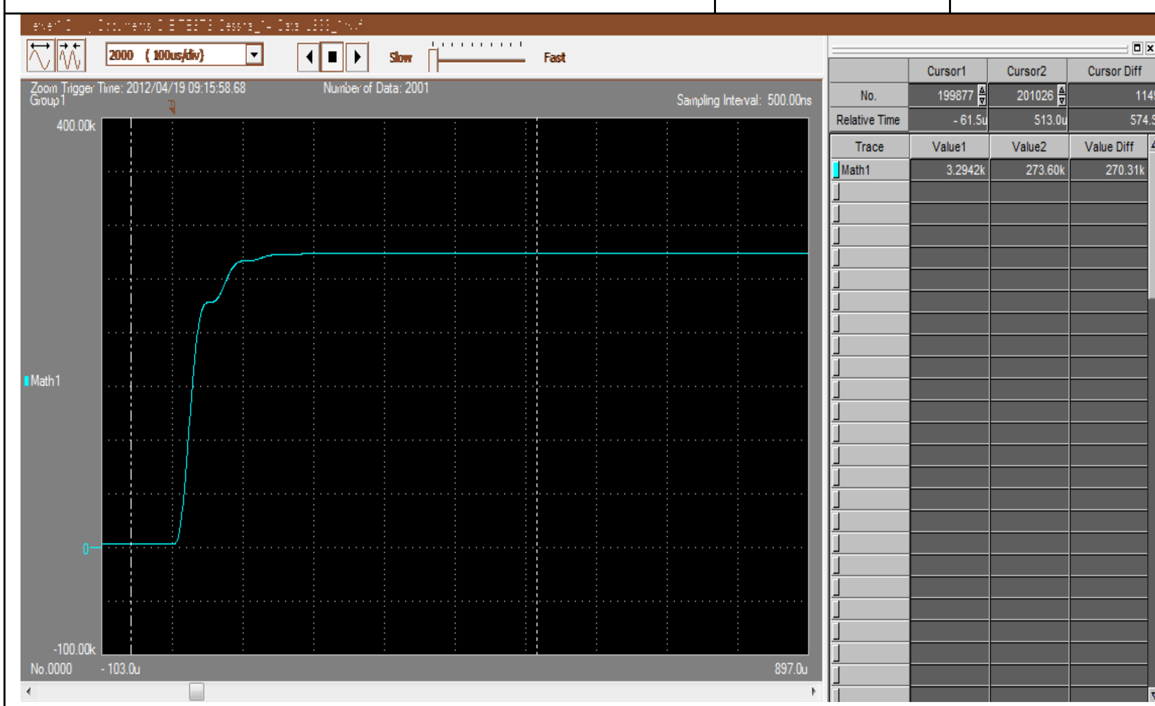
HIGH CURRENT – COMPONENT C*	Ip = 183 Amps	50 mS / Div

COMPONENT C* CHARGE TRANSFER	0.70 Coulombs

PANEL: LS-37

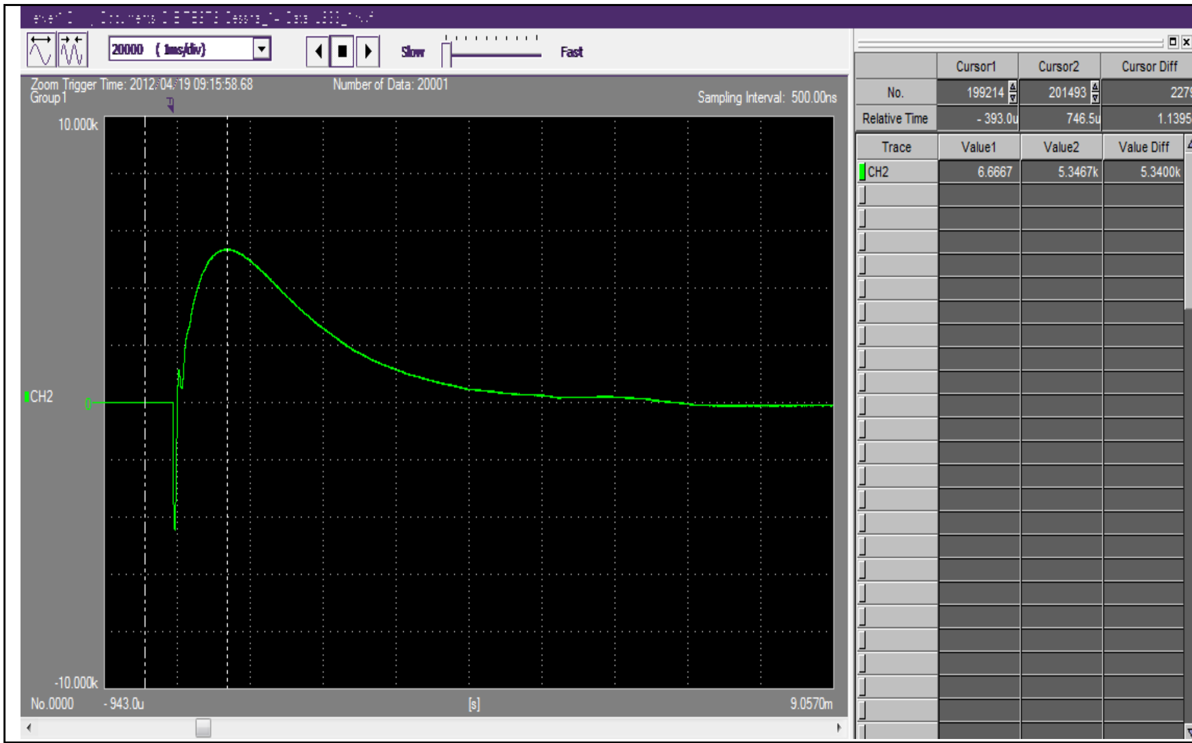


HIGH CURRENT – COMPONENT D	Ip = 94.8 KA	100 uS / Div

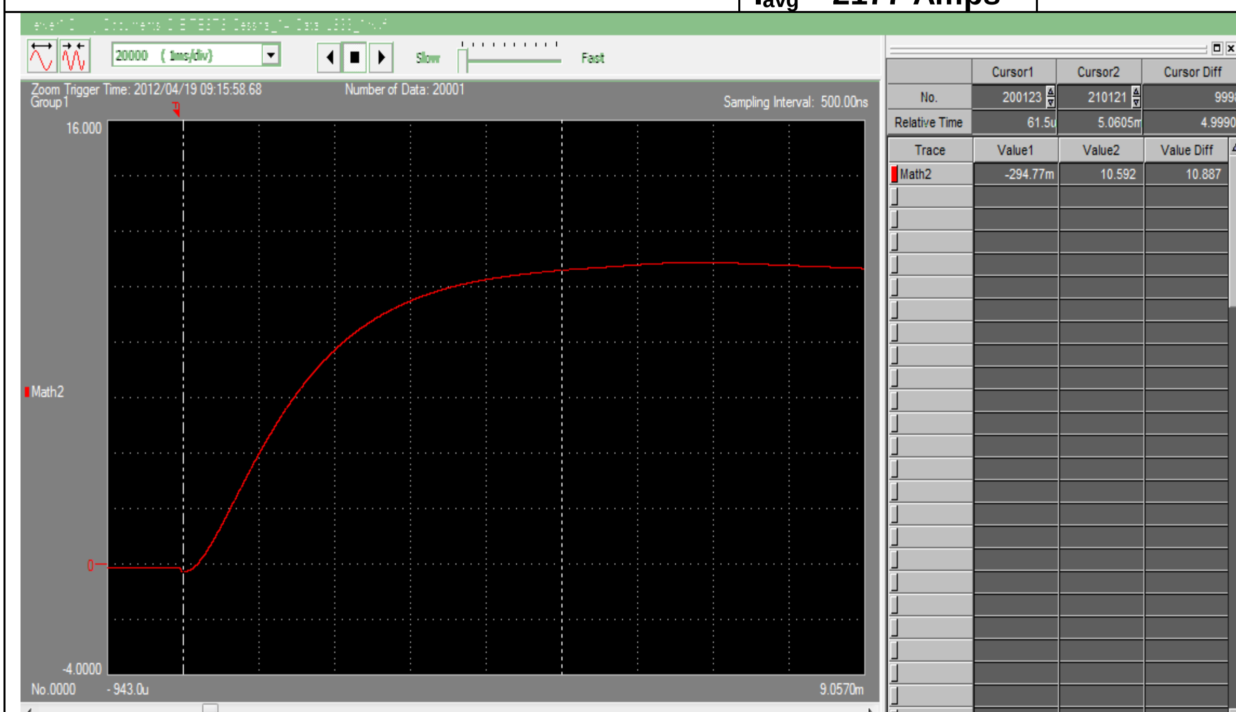


COMPONENT D ACTION INTEGRAL	AI = 270310 A^2-S

PANEL: LS-38

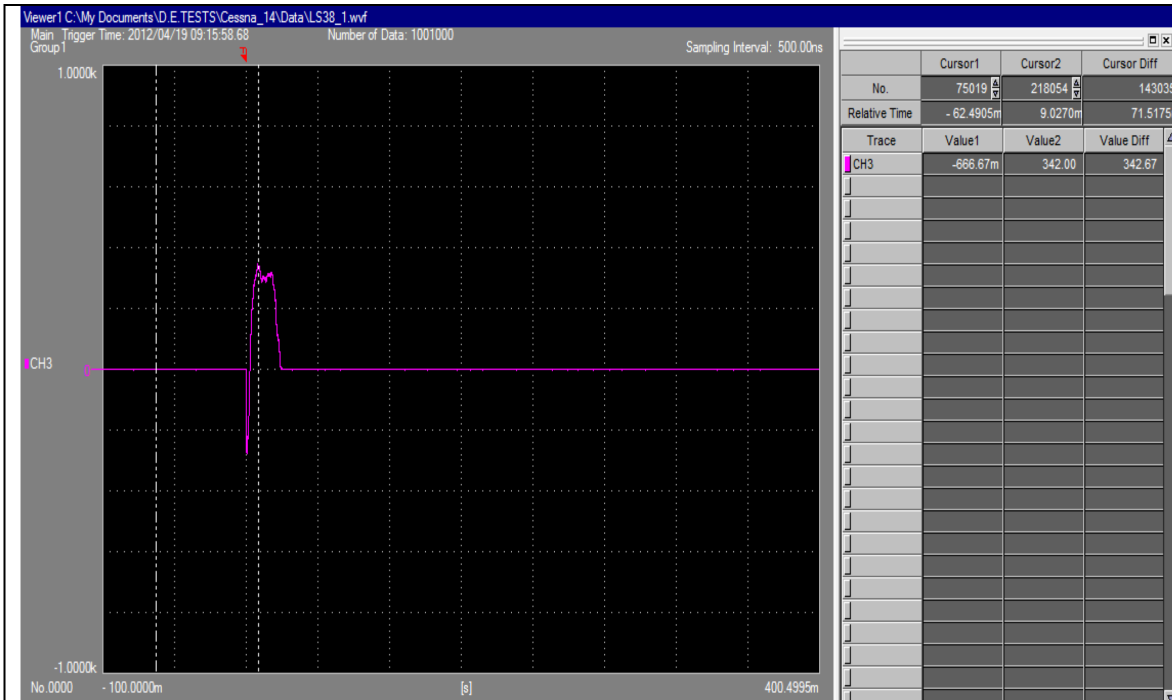


HIGH CURRENT – COMPONENT B	**I_P = 5340 Amps** **I_{avg} = 2177 Amps**	**1 mS / Div**

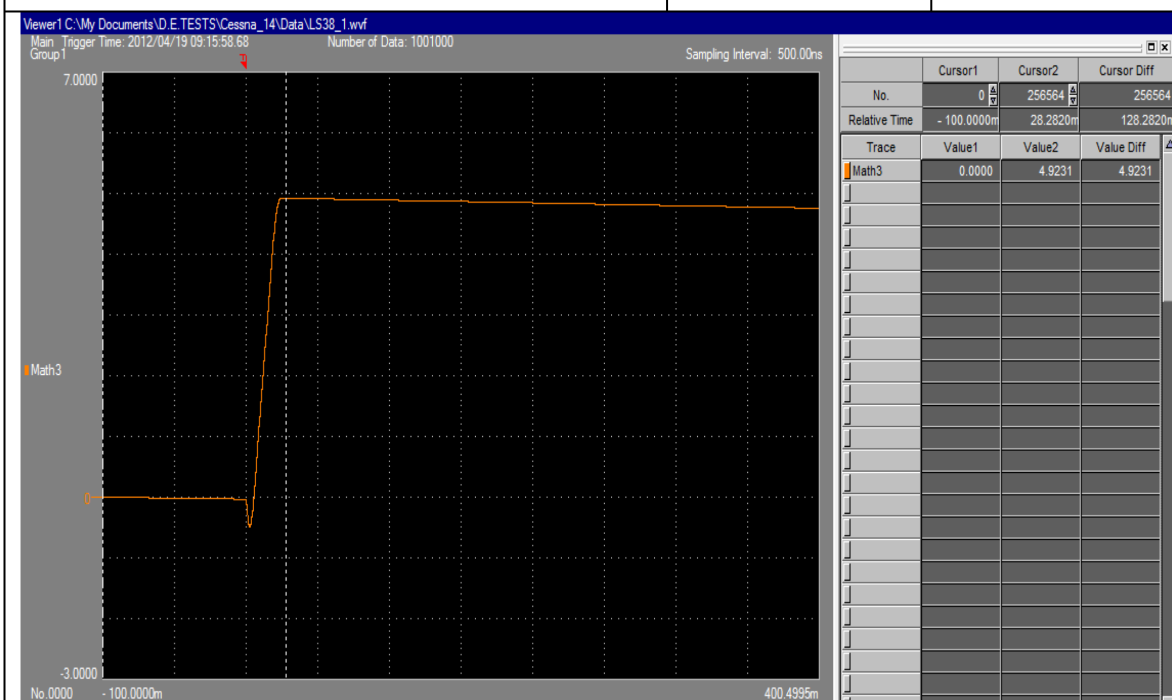


COMPONENT B CHARGE TRANSFER	**10.887 Coulombs**

PANEL: LS-38

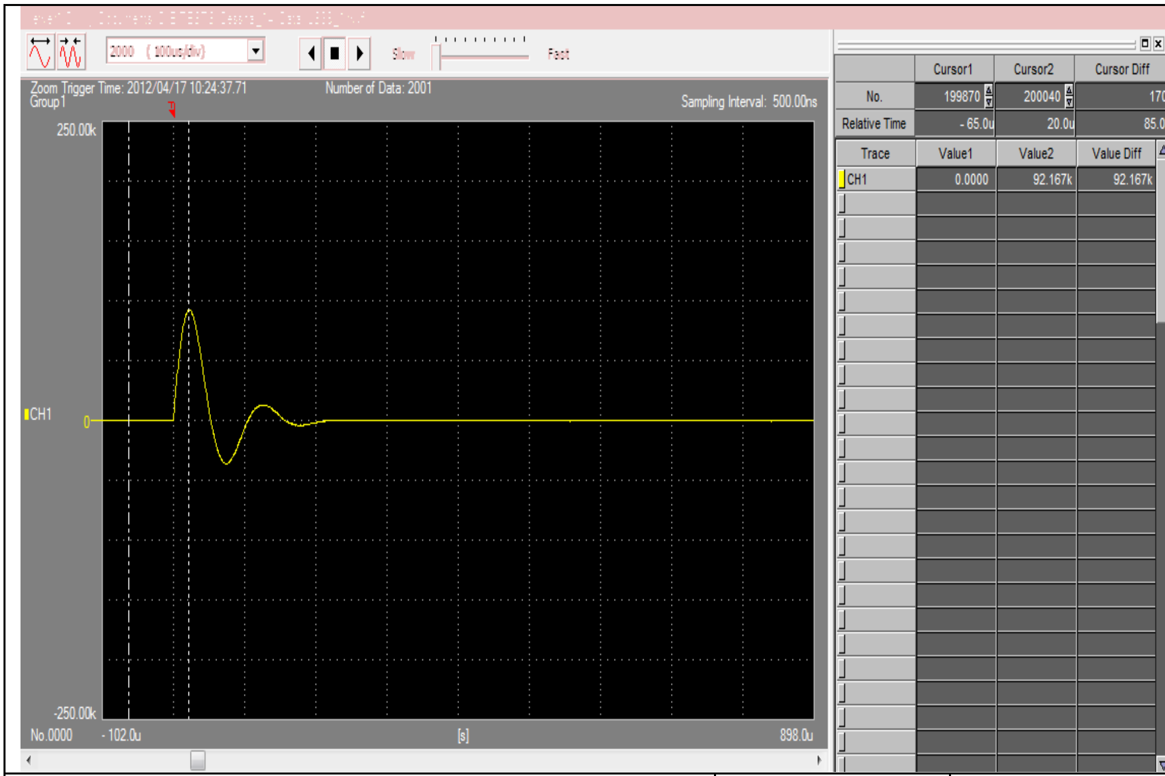


HIGH CURRENT – COMPONENT C*	Ip = 343 Amps	50 mS / Div

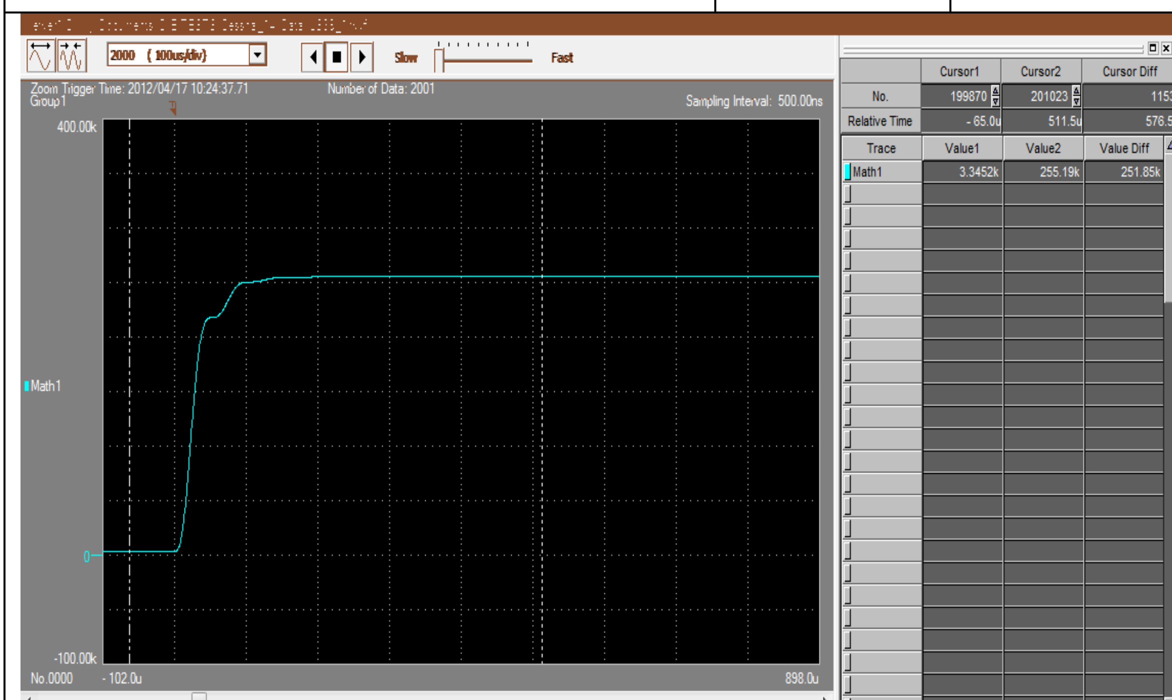


COMPONENT C* CHARGE TRANSFER	4.9 Coulombs

PANEL: LS-38

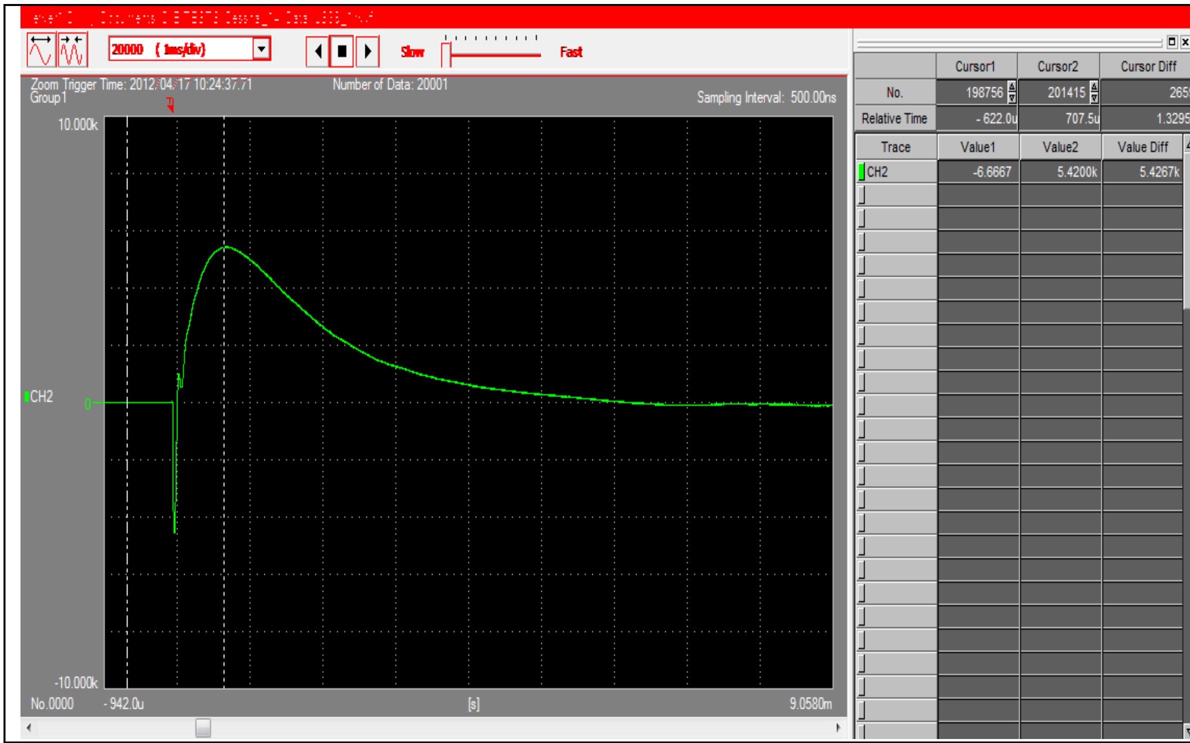


HIGH CURRENT – COMPONENT D	**Ip = 92.2 KA**	**100 uS / Div**

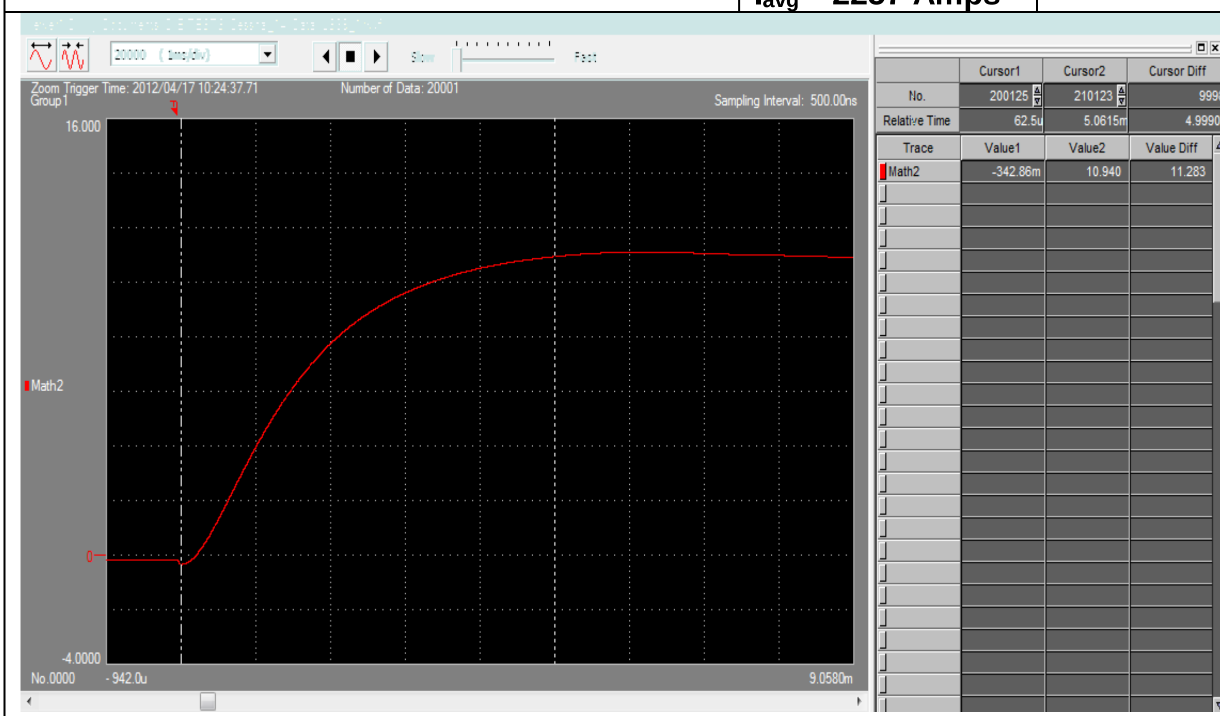


COMPONENT D ACTION INTEGRAL	**AI = 251850 A^2-S**

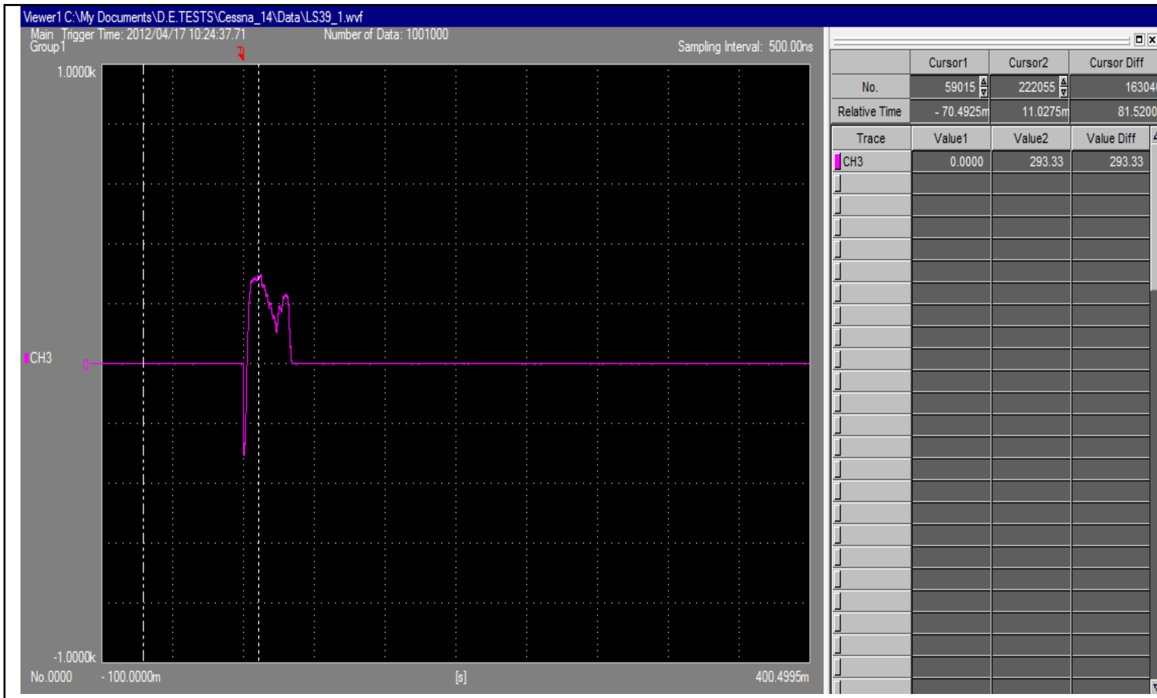
PANEL: LS-39



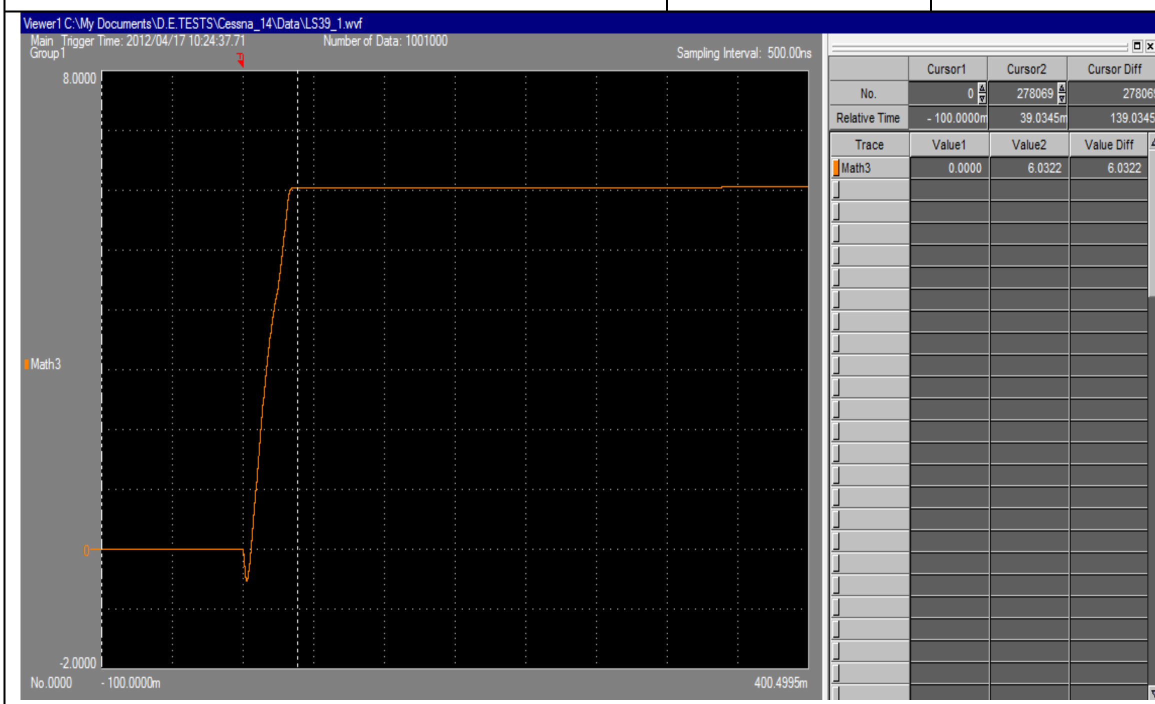
HIGH CURRENT – COMPONENT B	I_P = 5427 Amps I_{avg} = 2257 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.283 Coulombs
PANEL: LS-39	

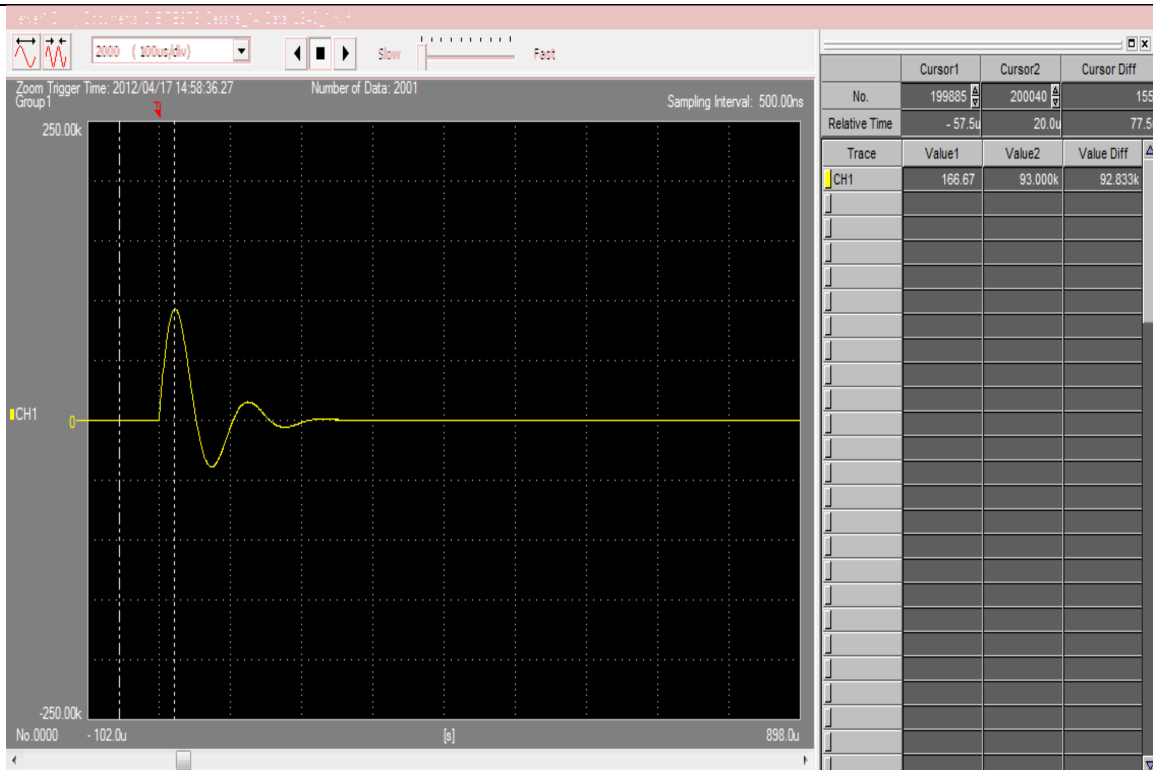


HIGH CURRENT – COMPONENT C*	Ip = 293 Amps	50 mS / Div

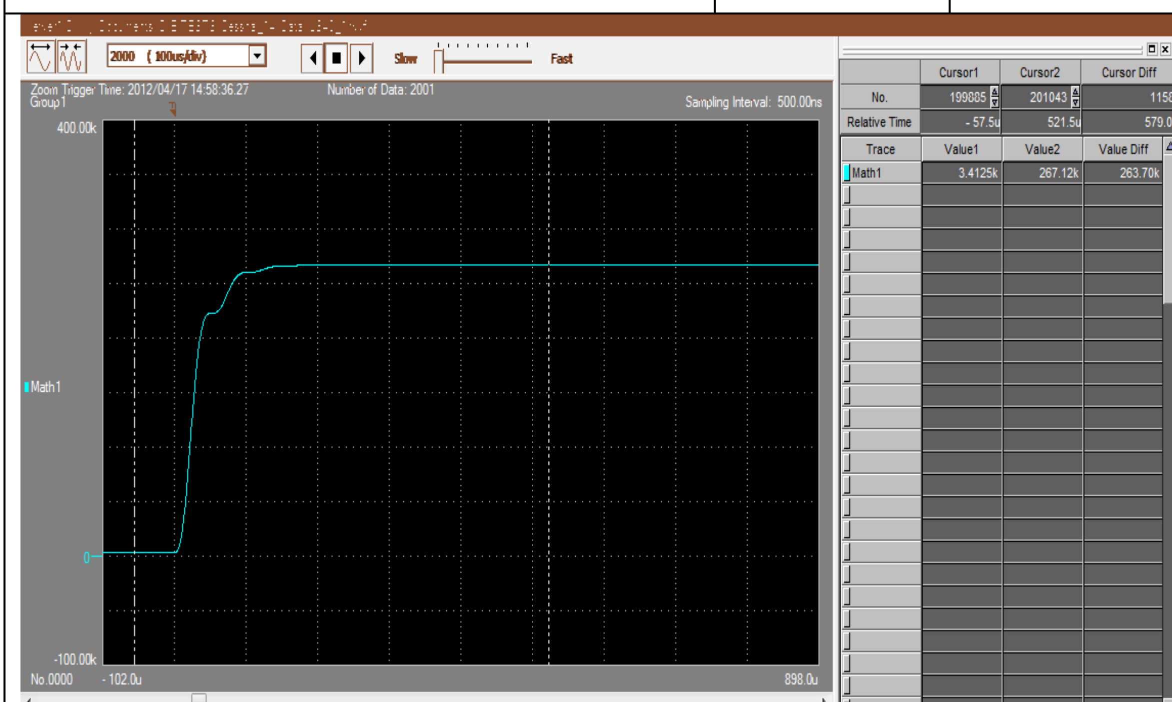


COMPONENT C* CHARGE TRANSFER	6.0 Coulombs

PANEL: LS-39

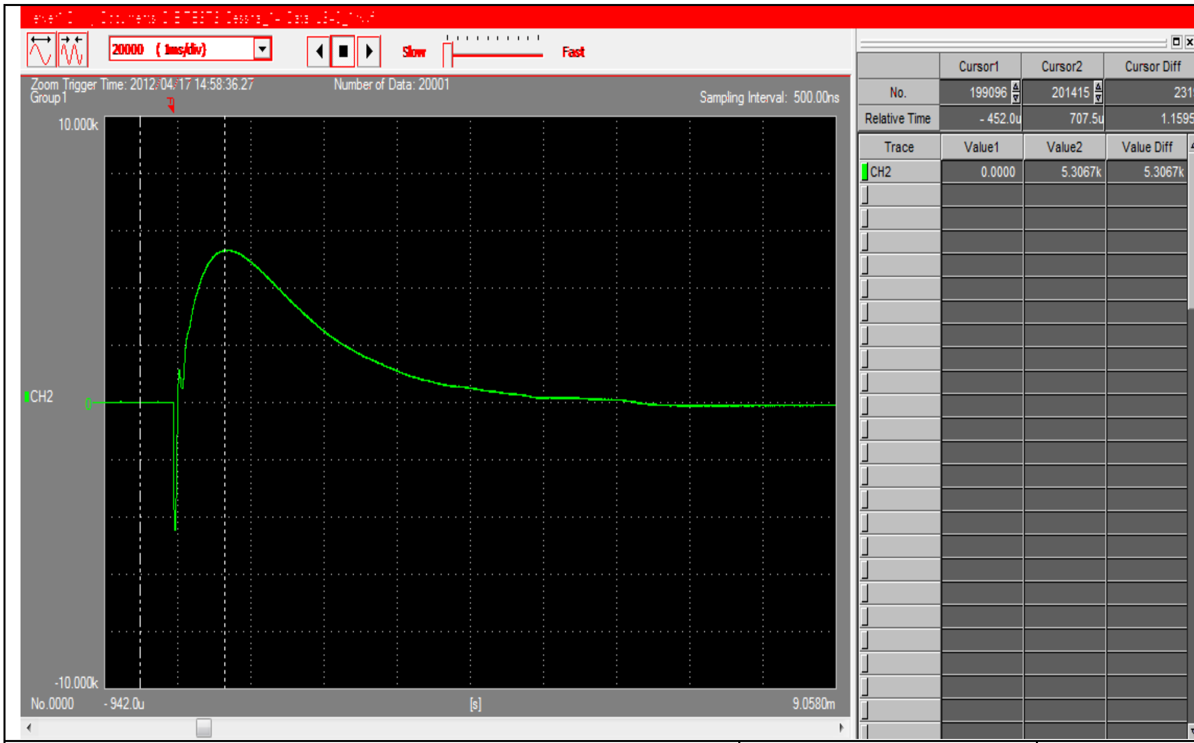


HIGH CURRENT – COMPONENT D	Ip = 92.8 KA	100 uS / Div

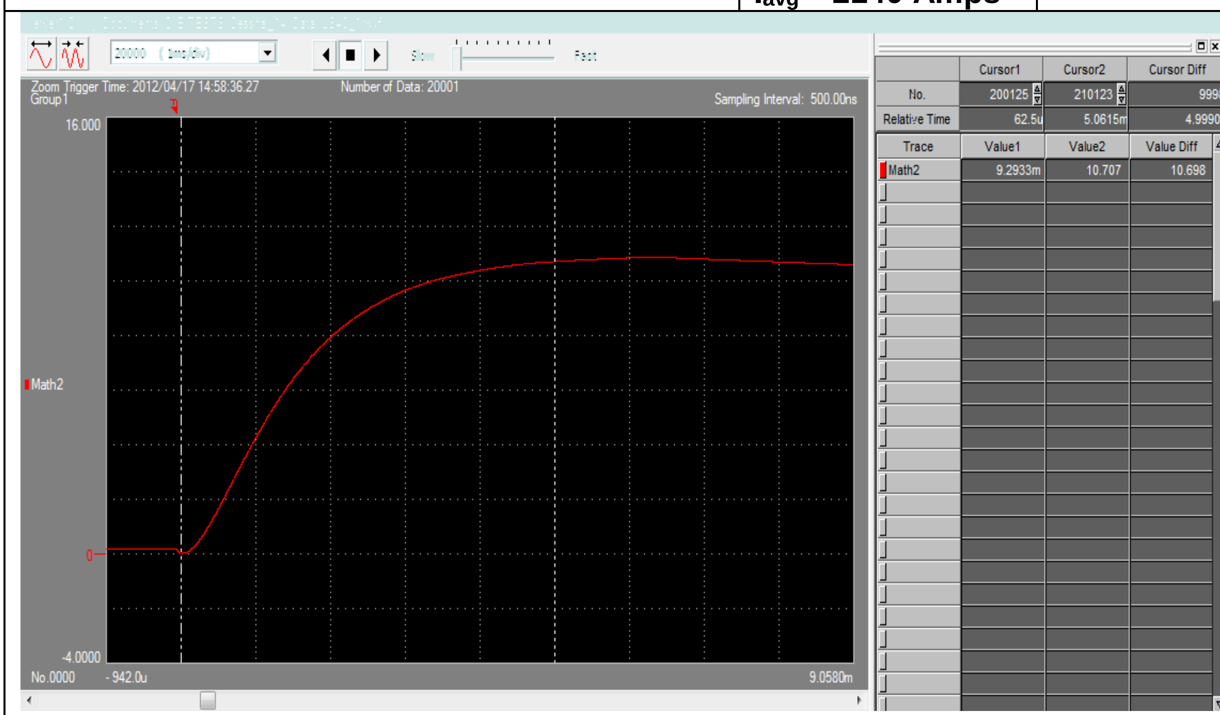


COMPONENT D ACTION INTEGRAL	AI = 263700 A^2-S

PANEL: LS-40

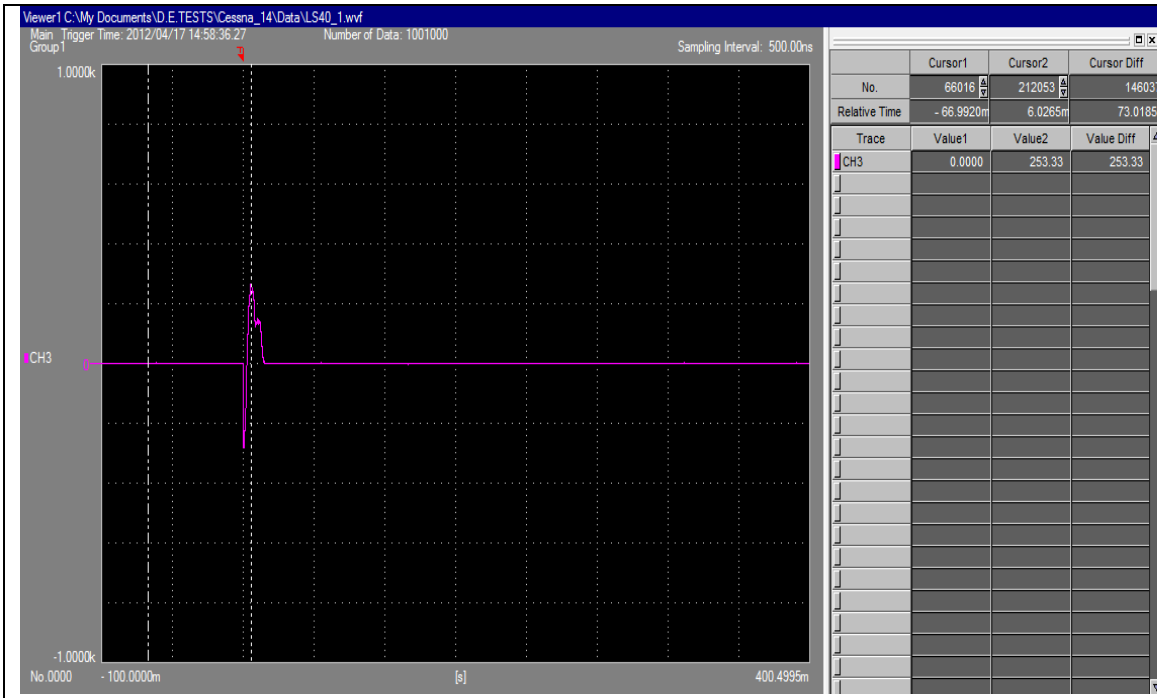


HIGH CURRENT – COMPONENT B	**I_P = 5307 Amps** **I_{avg} = 2140 Amps**	**1 mS / Div**

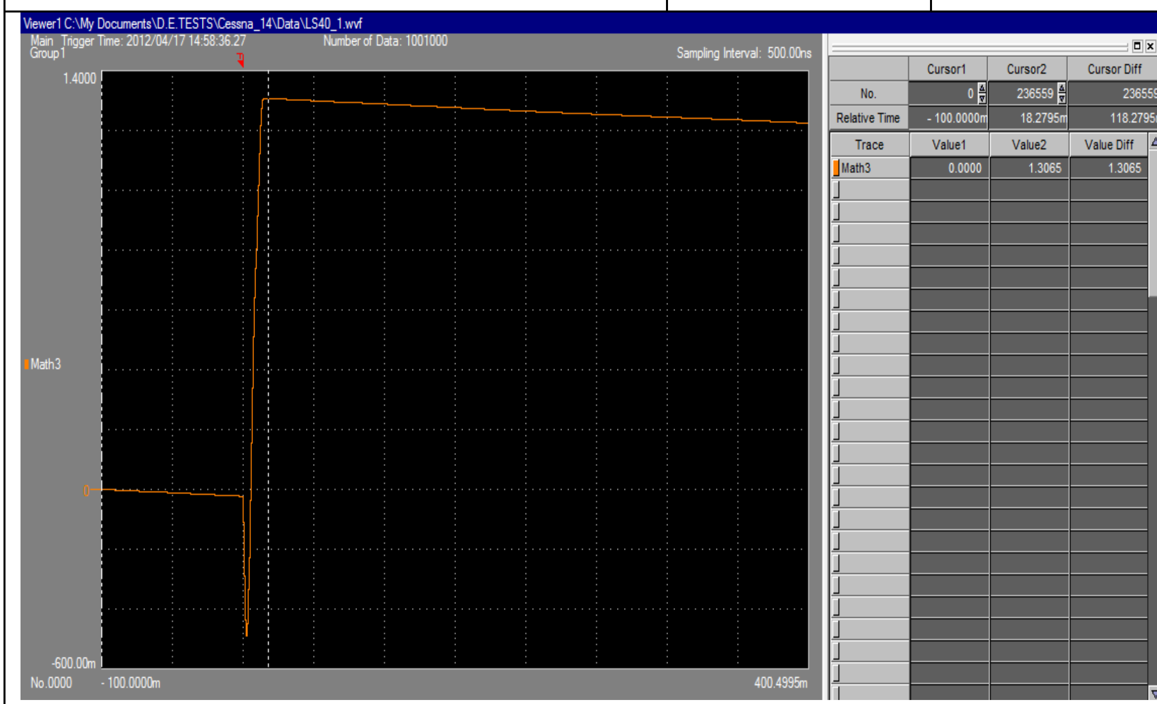


COMPONENT B CHARGE TRANSFER	**10.698 Coulombs**

PANEL: LS-40

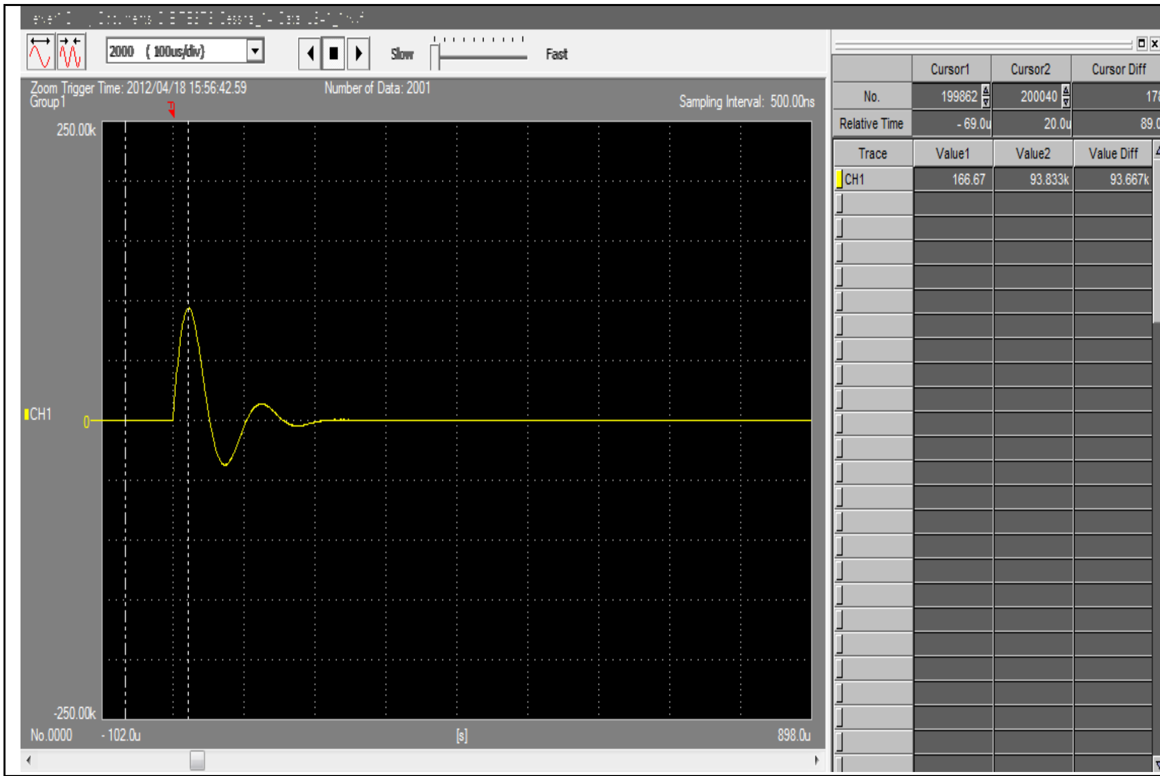


HIGH CURRENT – COMPONENT C*	Ip = 253 Amps	50 mS / Div

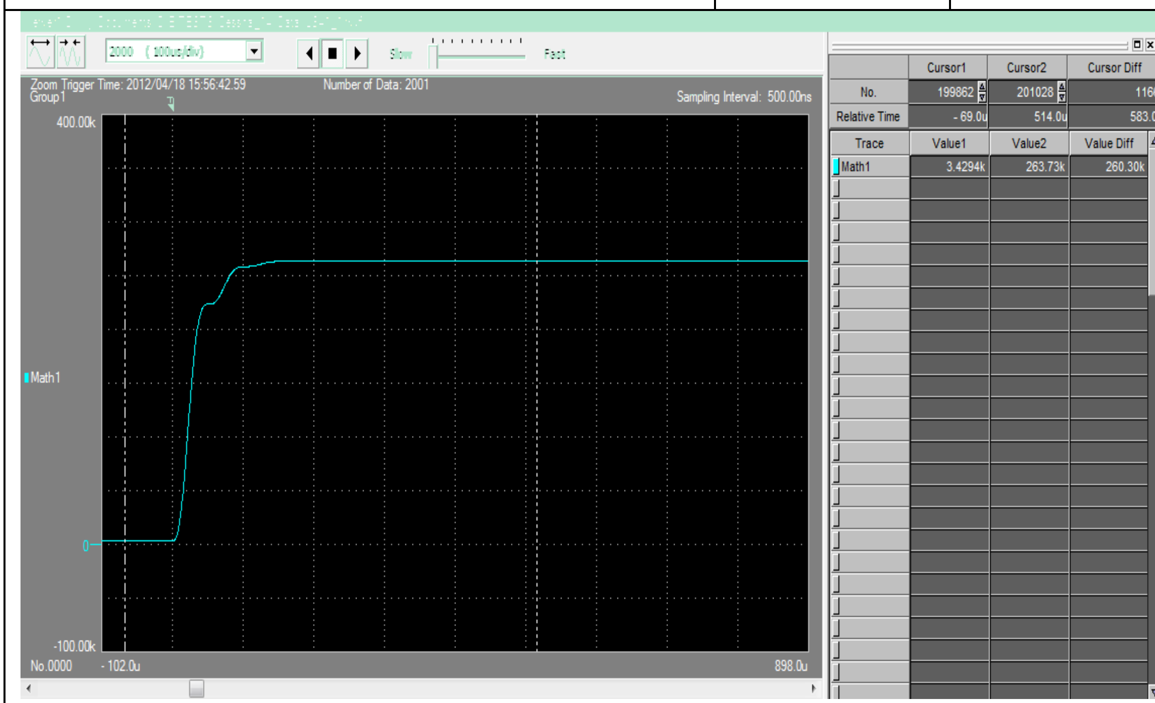


COMPONENT C* CHARGE TRANSFER	1.3 Coulombs

PANEL: LS-40

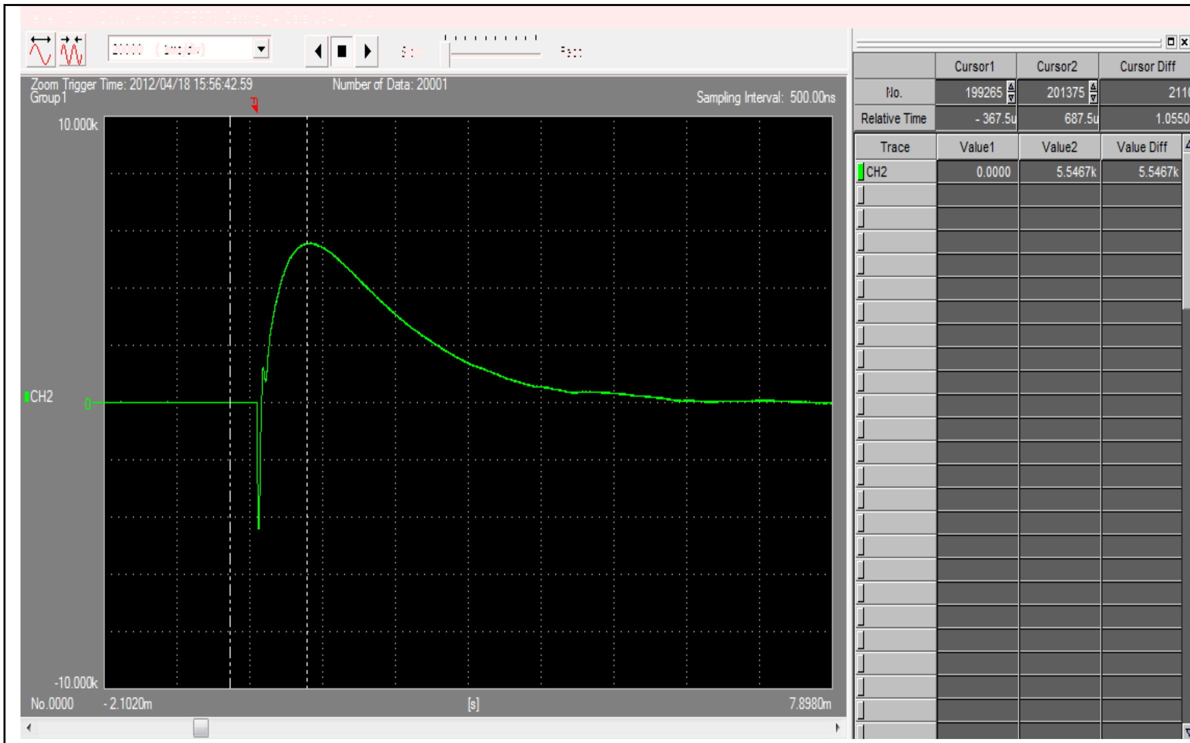


HIGH CURRENT – COMPONENT D	Ip = 93.7 KA	100 uS / Div

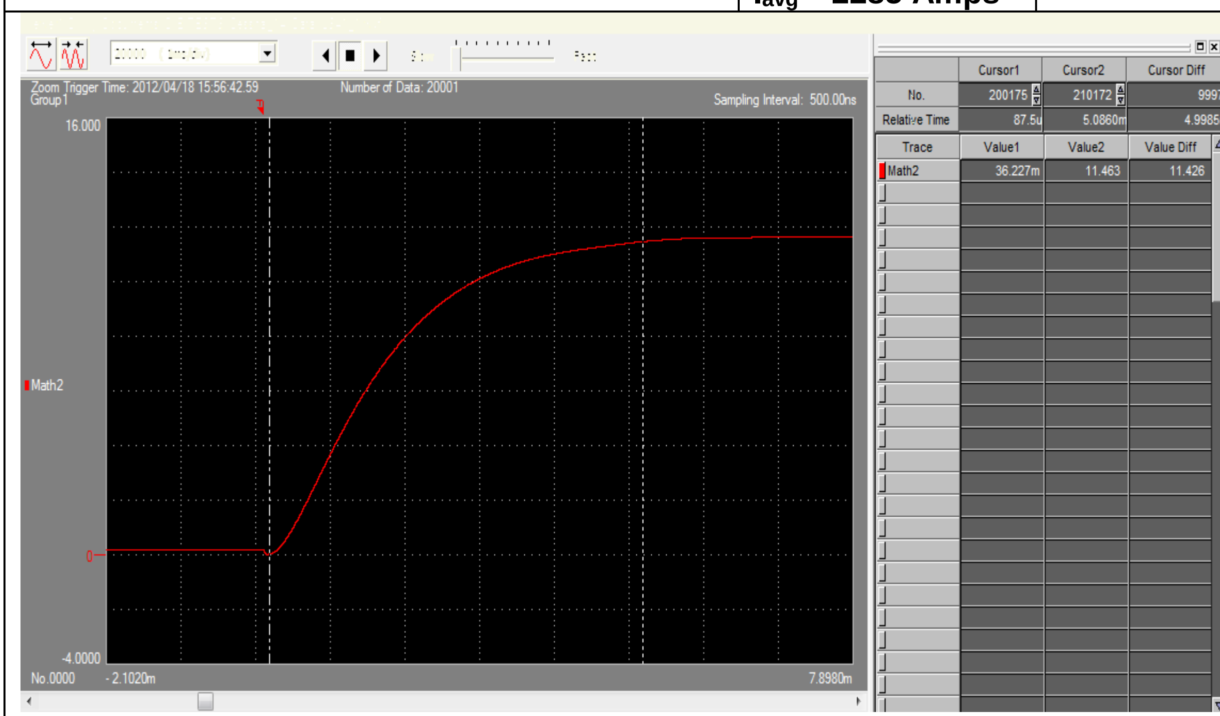


COMPONENT D ACTION INTEGRAL	AI = 260300 A^2-S

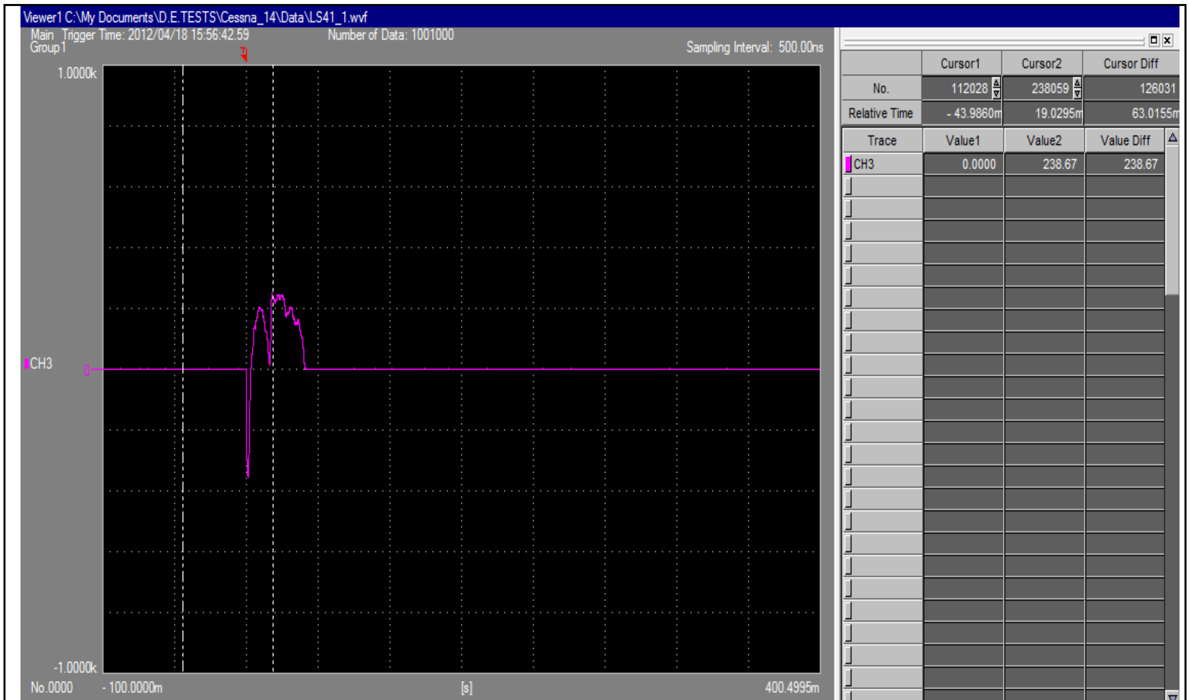
PANEL: LS-41



HIGH CURRENT – COMPONENT B	**I_P = 5547 Amps** **I_{avg} = 2285 Amps**	**1 mS / Div**

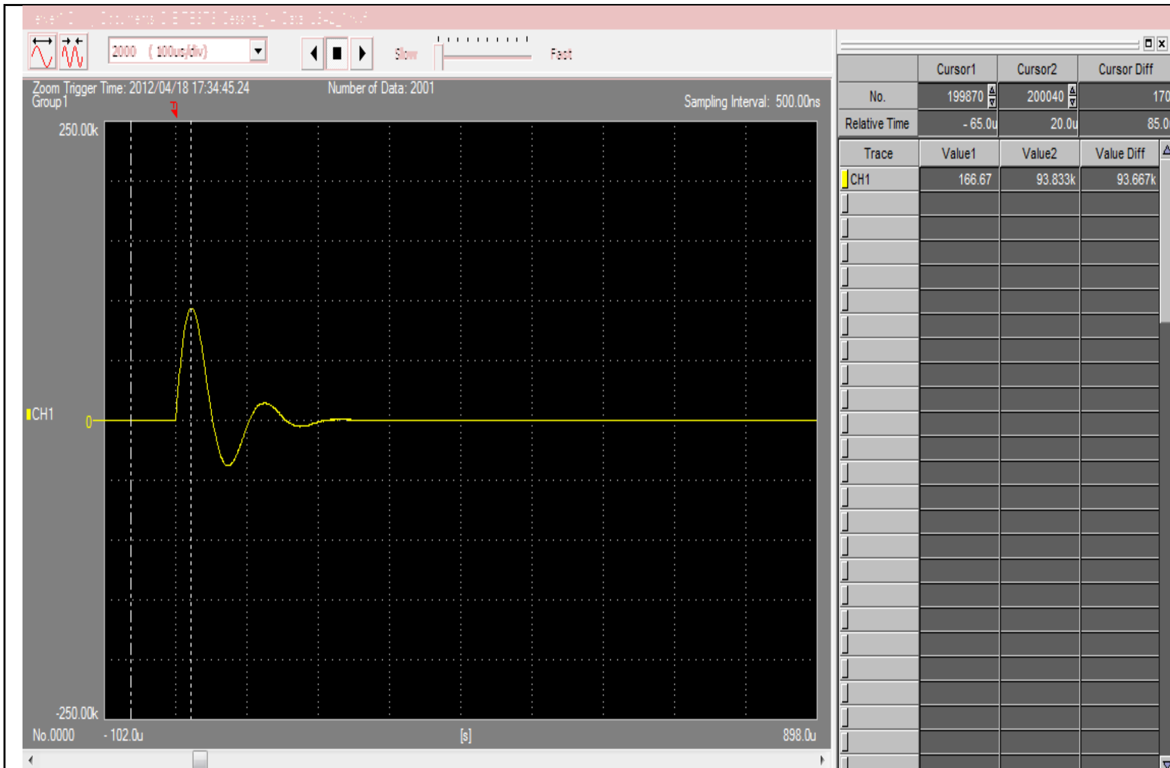


COMPONENT B CHARGE TRANSFER	**11.426 Coulombs**
PANEL: LS-41	

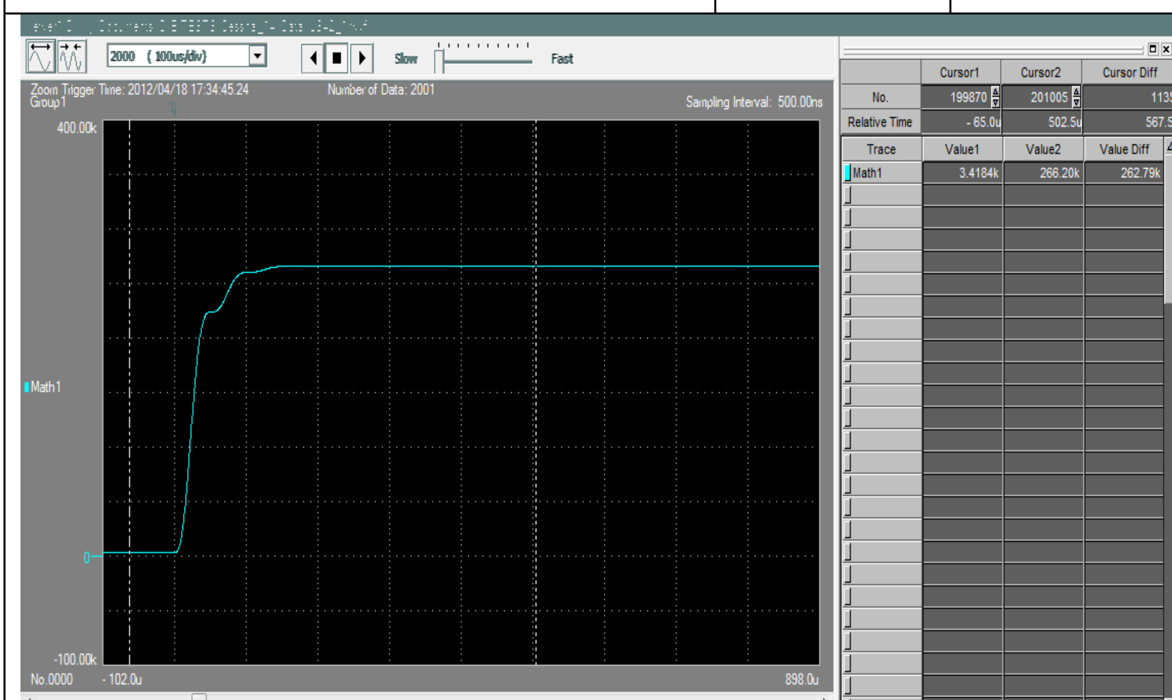


HIGH CURRENT – COMPONENT C*	Ip = 239 Amps	50 mS / Div

COMPONENT C* CHARGE TRANSFER	5.4 Coulombs
PANEL: LS-41	

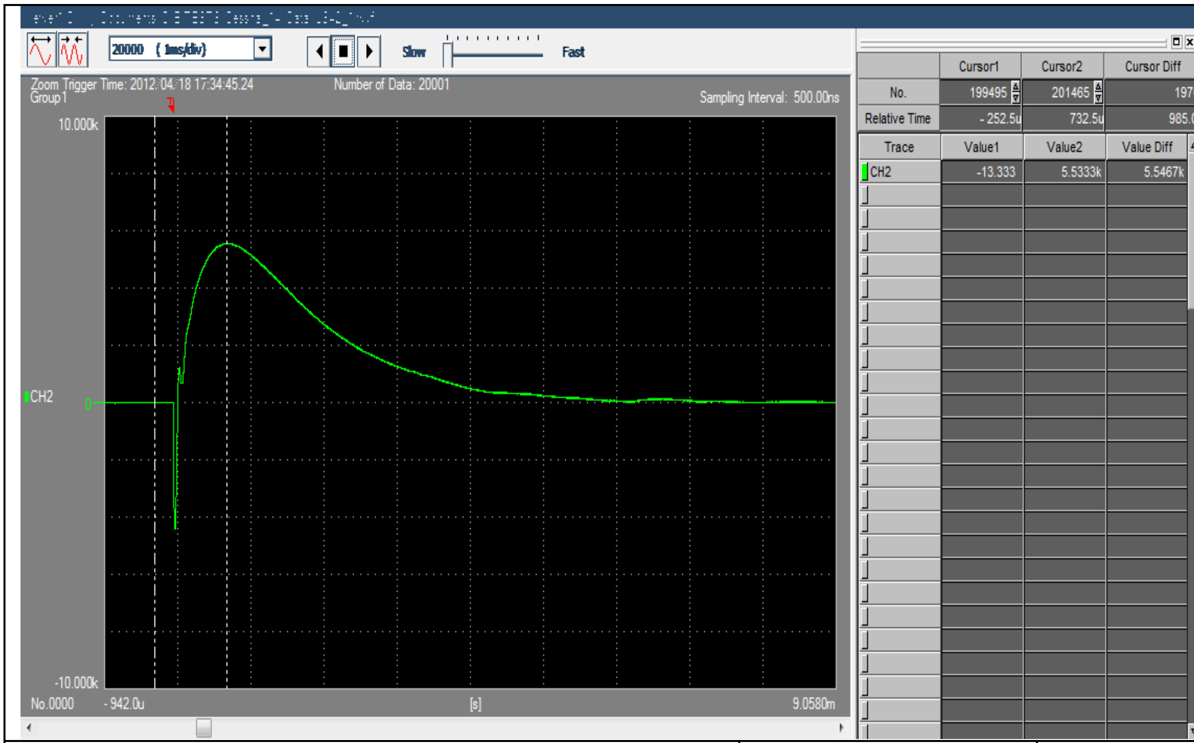


HIGH CURRENT – COMPONENT D	Ip = 93.7 KA	100 uS / Div

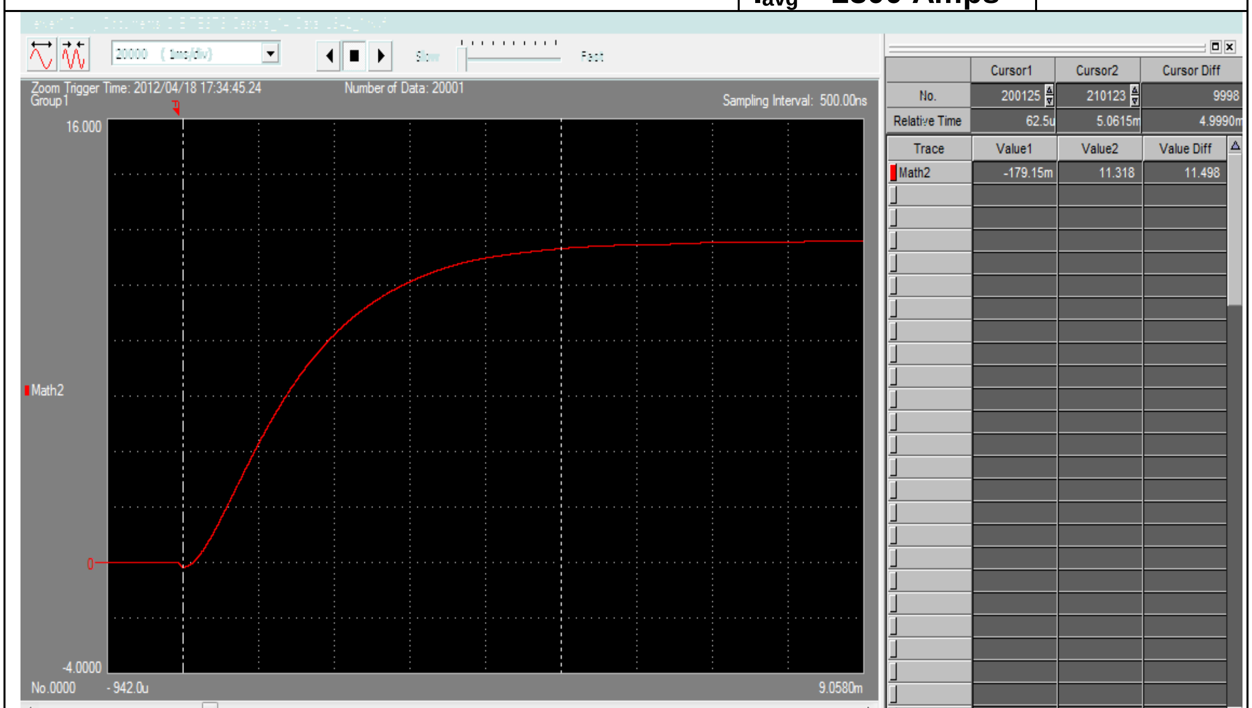


COMPONENT D ACTION INTEGRAL	AI = 262790 A^2-S

PANEL: LS-42

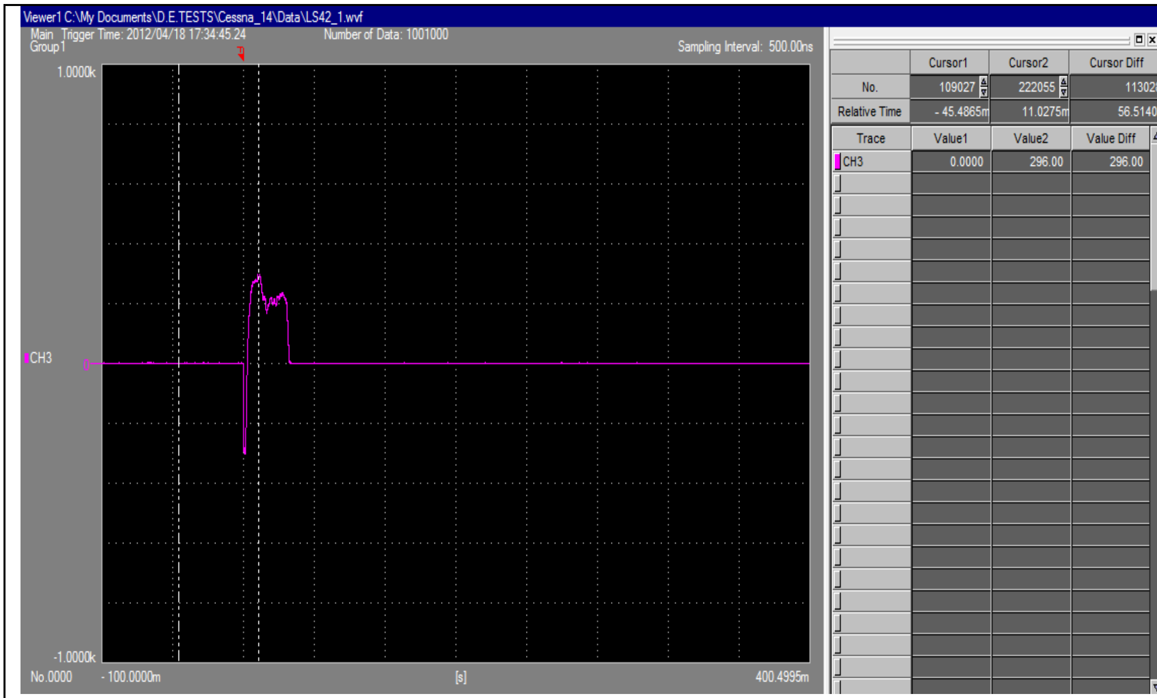


HIGH CURRENT – COMPONENT B	I_P = 5547 Amps I_{avg} = 2300 Amps	1 mS / Div

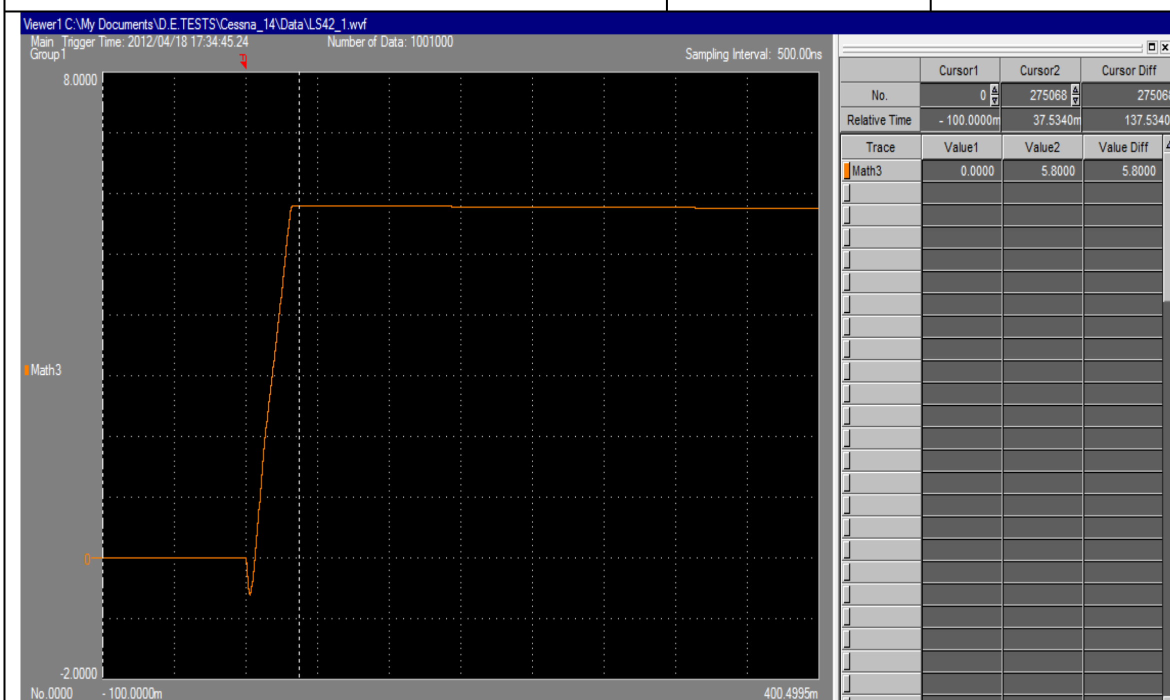


COMPONENT B CHARGE TRANSFER	11.498 Coulombs

PANEL: LS-42

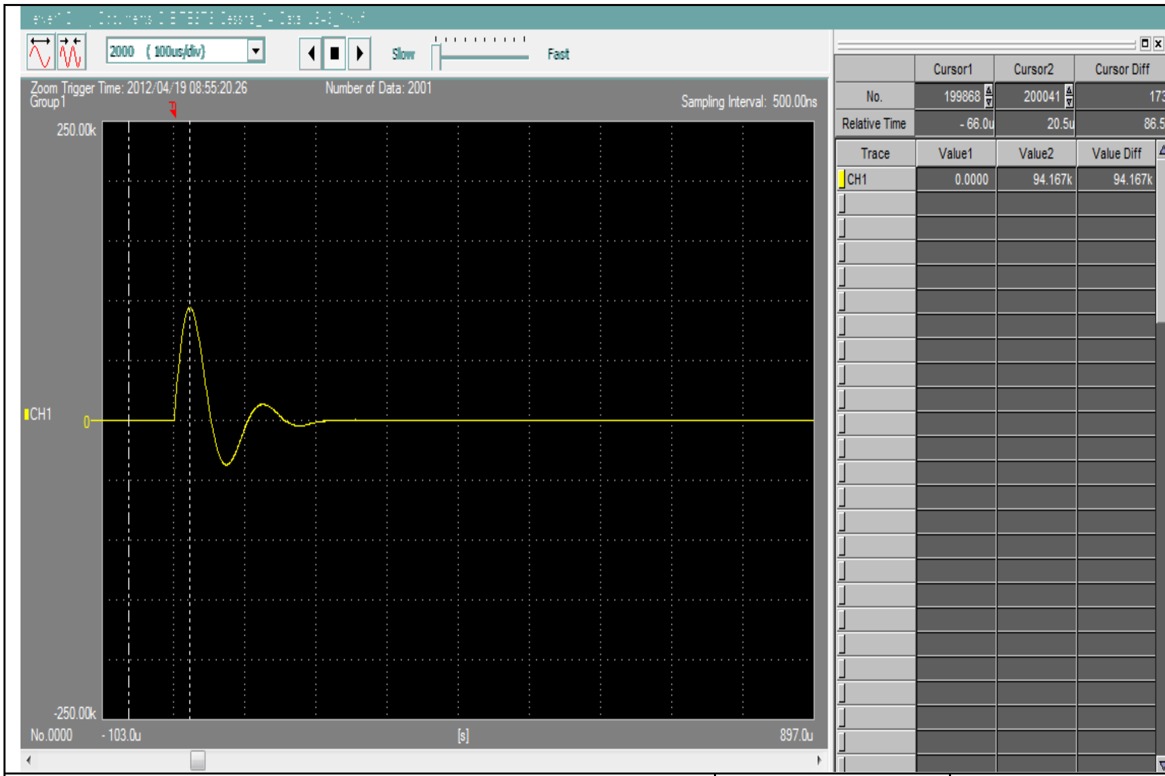


HIGH CURRENT – COMPONENT C*	Ip = 296 Amps	50 mS / Div

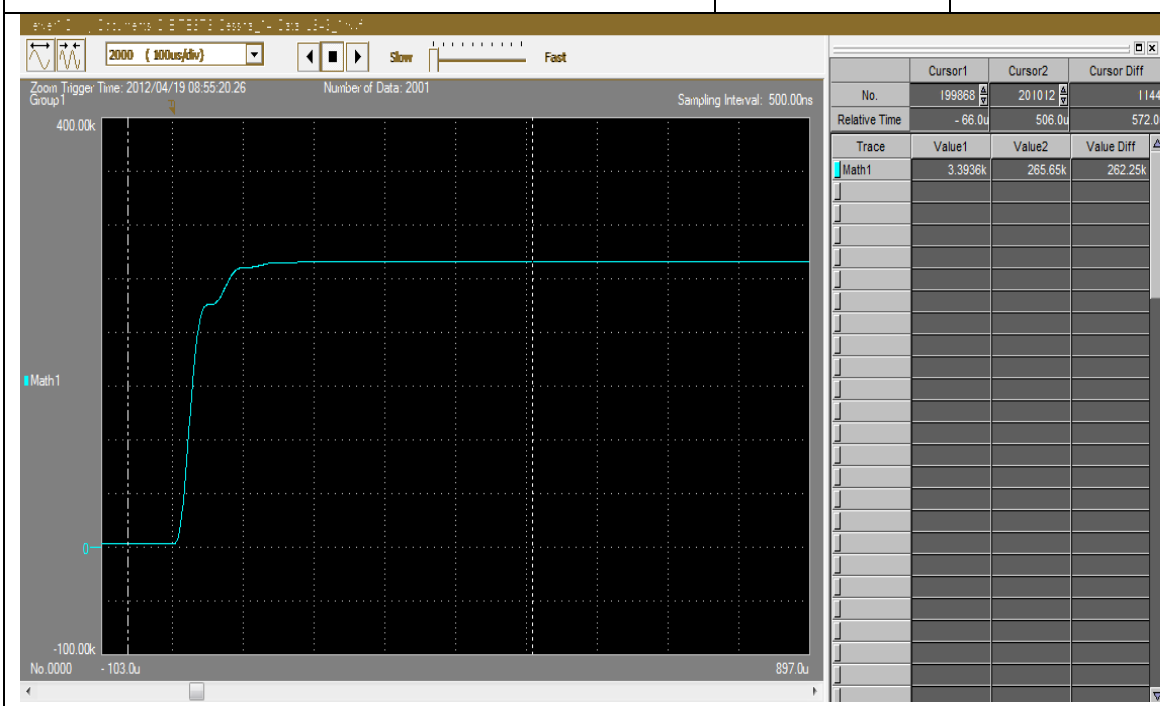


COMPONENT C* CHARGE TRANSFER	5.8 Coulombs

PANEL: LS-42

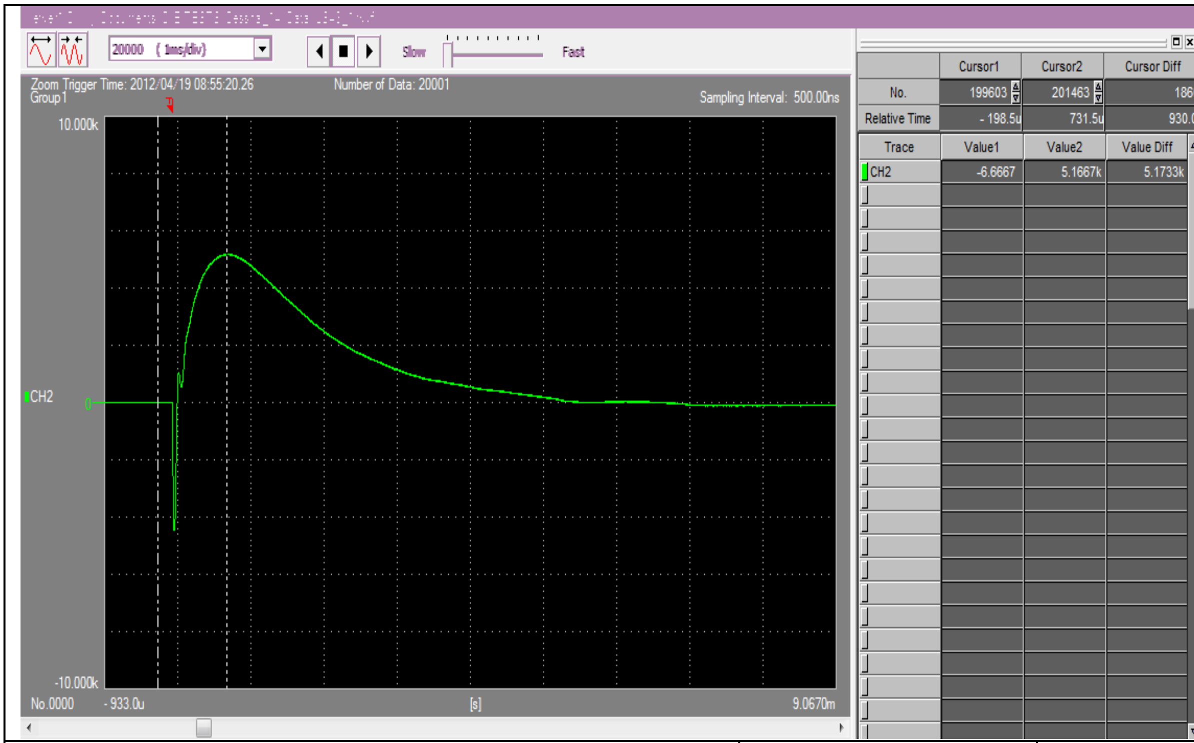


HIGH CURRENT – COMPONENT D	Ip = 94.2 KA	100 uS / Div

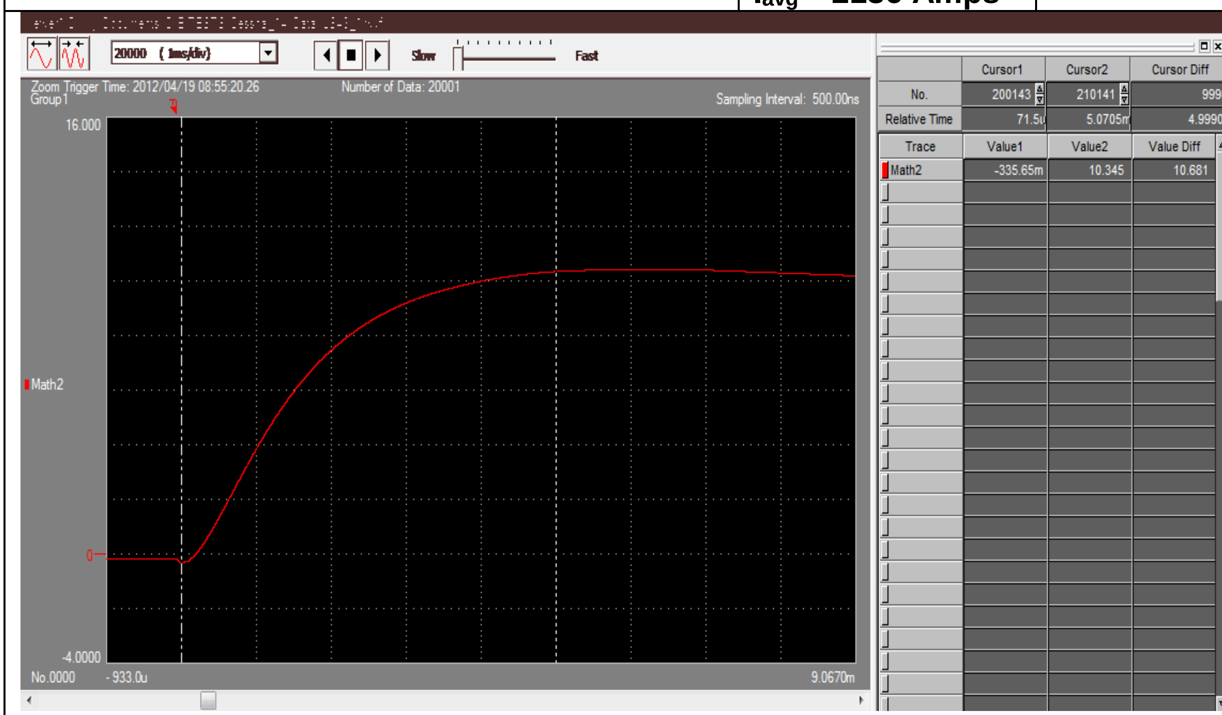


COMPONENT D ACTION INTEGRAL	AI = 262250 A^2-S

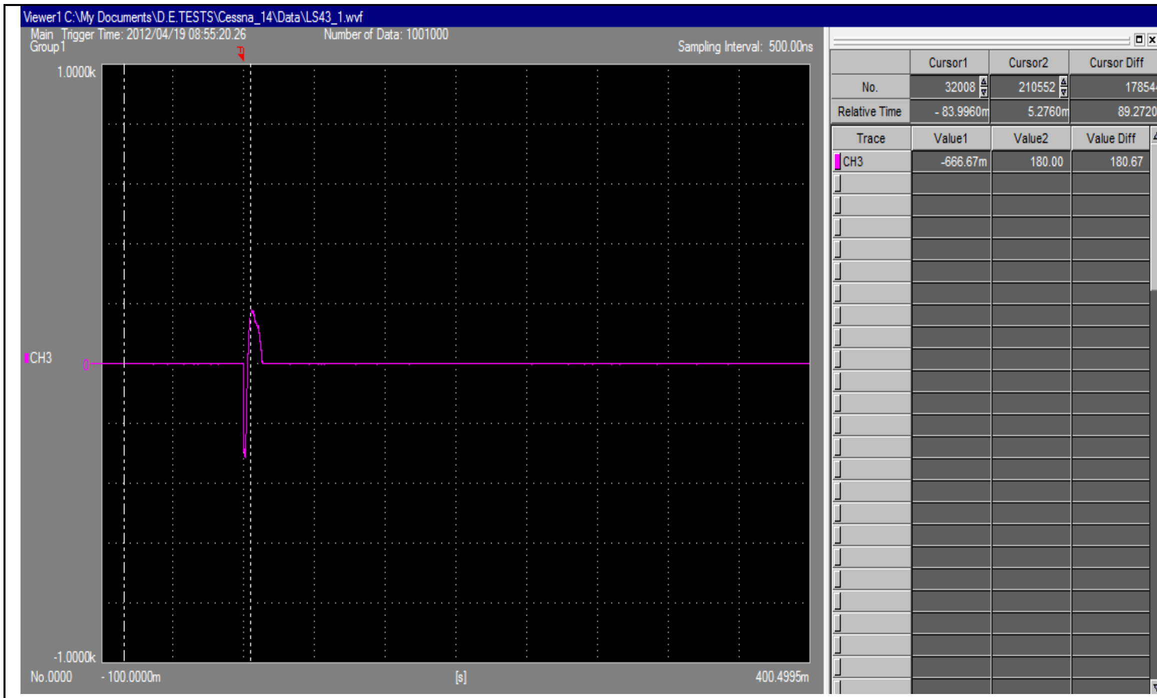
PANEL: LS-43



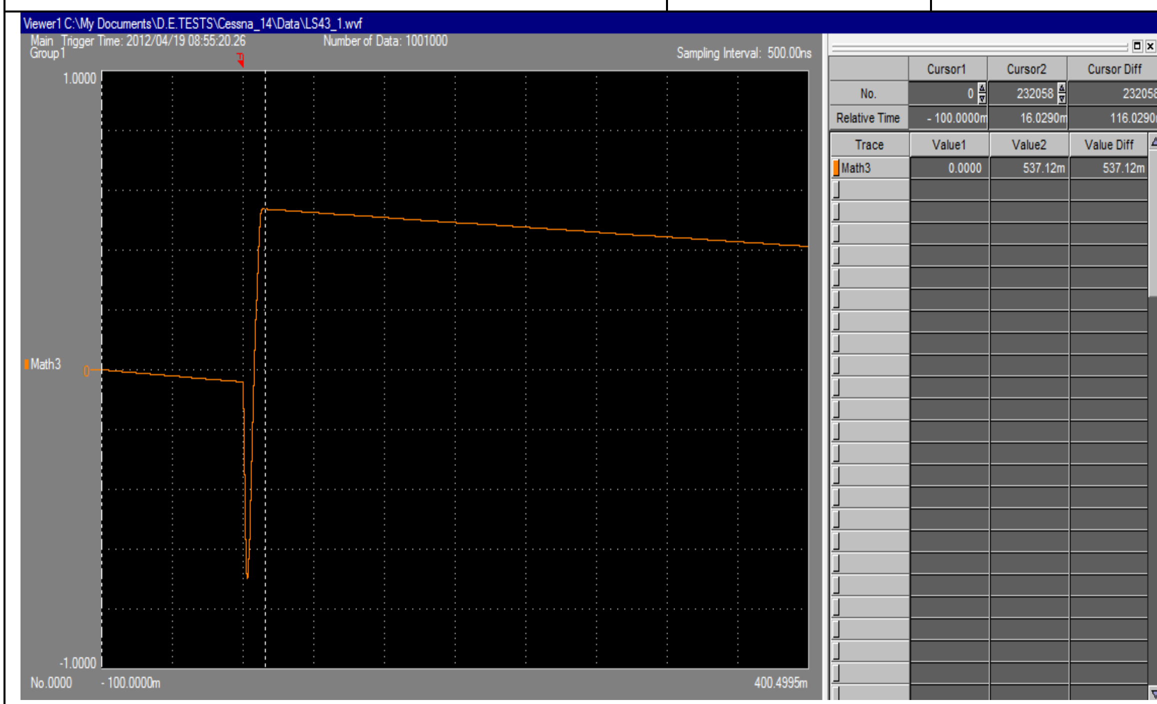
HIGH CURRENT – COMPONENT B	I_P = 5173 Amps I_{avg} = 2136 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.681 Coulombs
PANEL: LS-43	

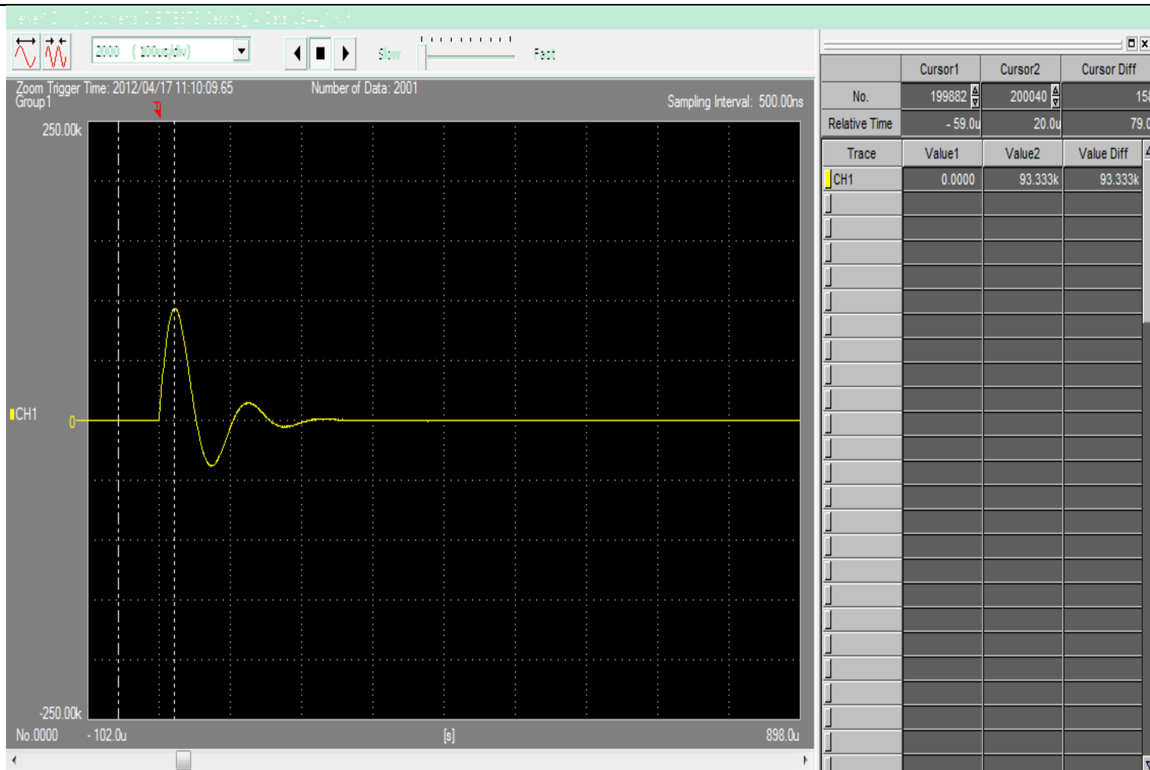


HIGH CURRENT – COMPONENT C*	Ip = 181 Amps	50 mS / Div

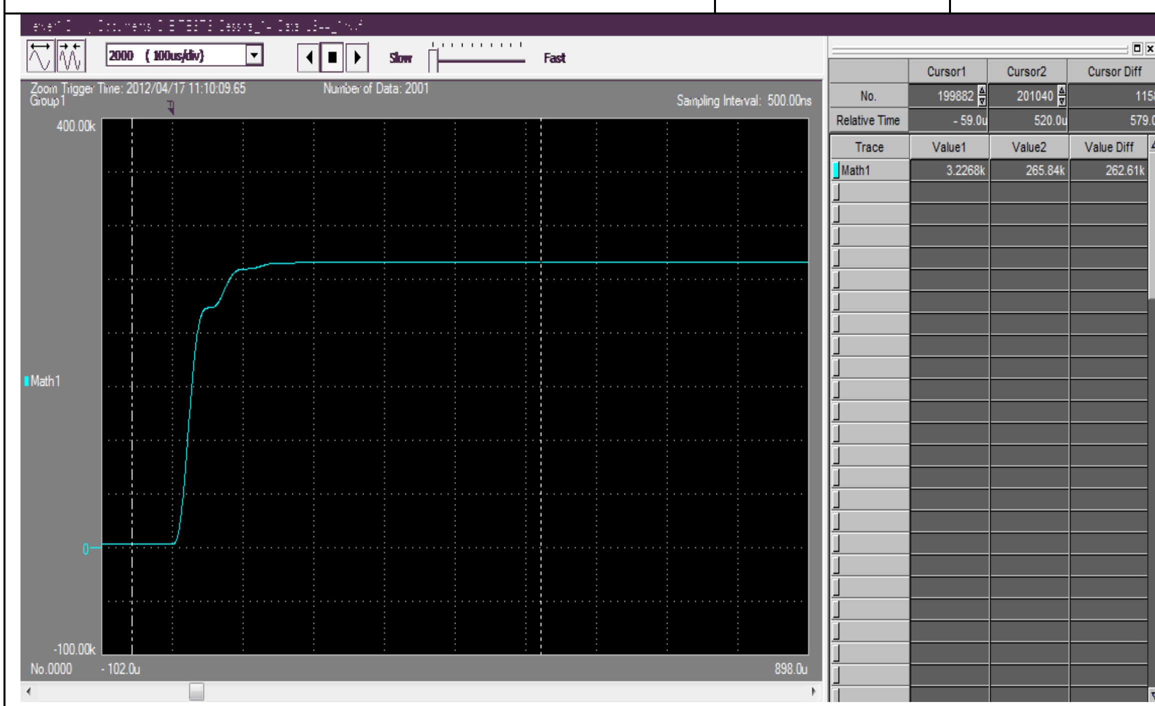


COMPONENT C* CHARGE TRANSFER	0.54 Coulombs

PANEL: LS-43

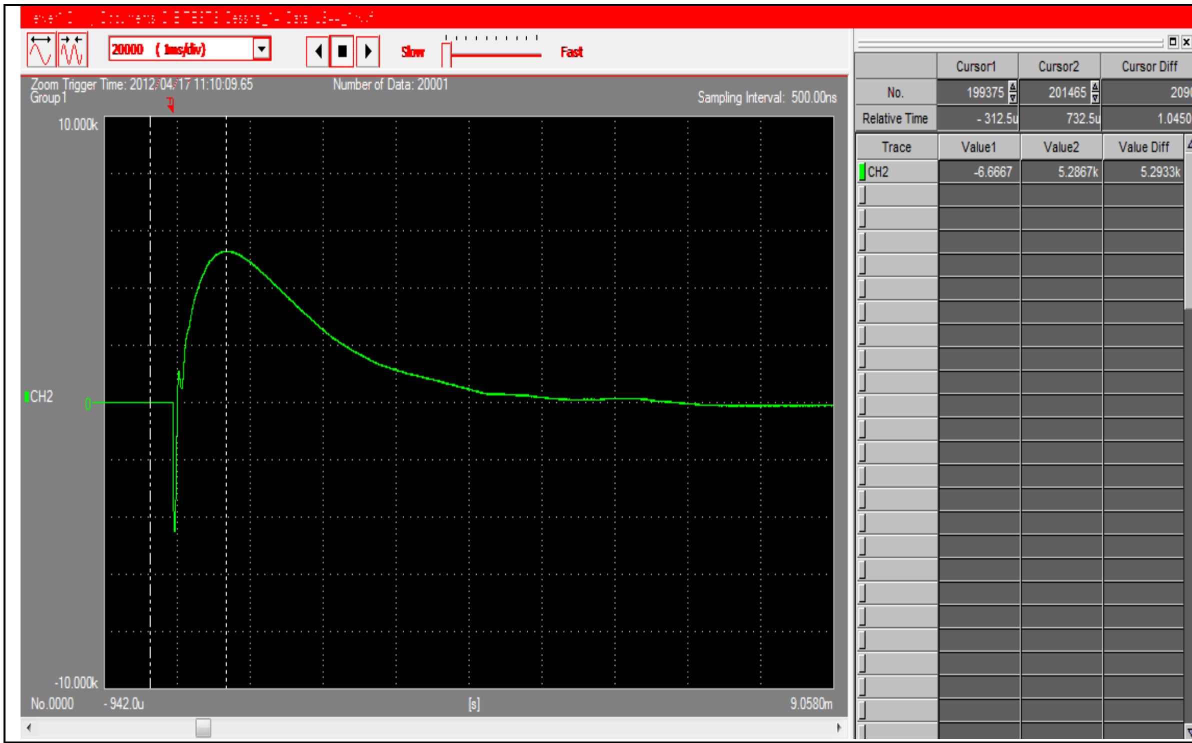


HIGH CURRENT – COMPONENT D	Ip = 93.3 KA	100 uS / Div

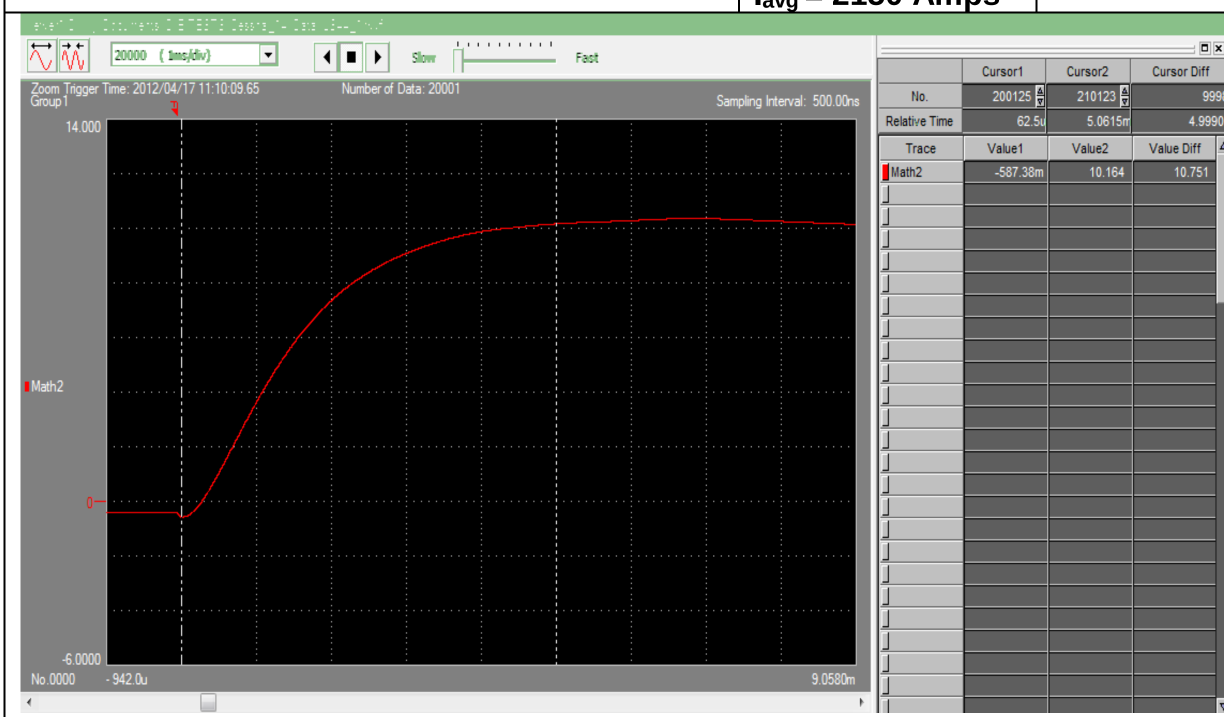


COMPONENT D ACTION INTEGRAL	AI = 262610 A^2-S

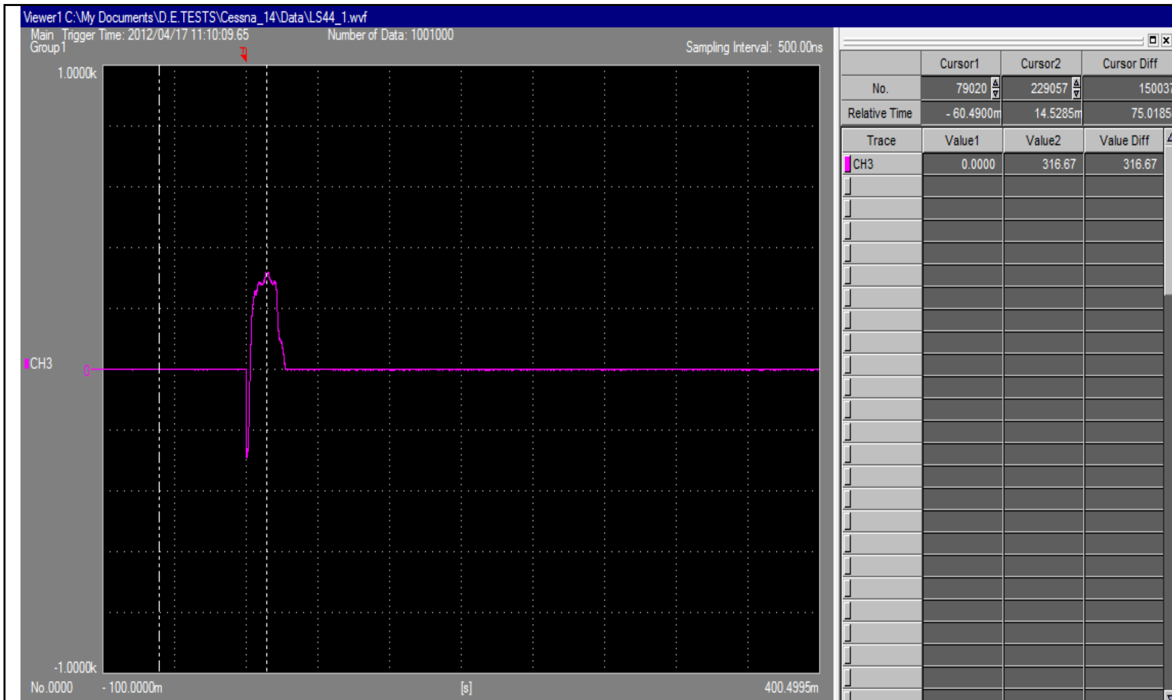
PANEL: LS-44



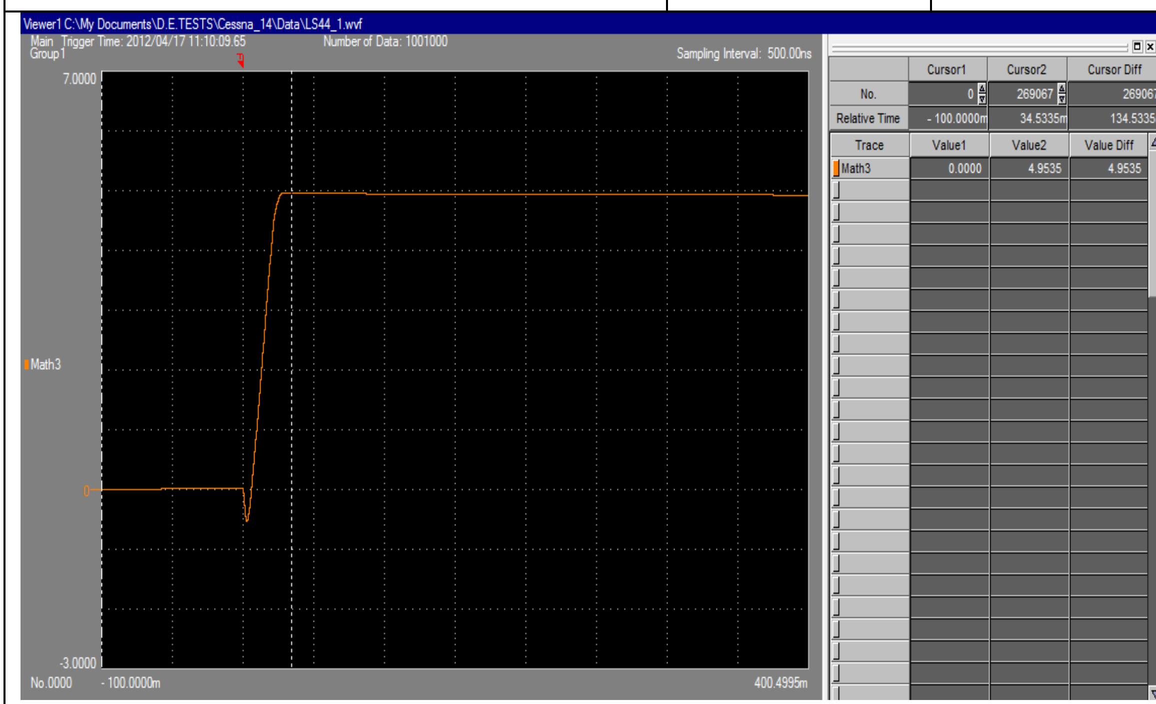
HIGH CURRENT – COMPONENT B	I_P = 5293 Amps I_{avg} = 2150 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.751 Coulombs
PANEL: LS-44	

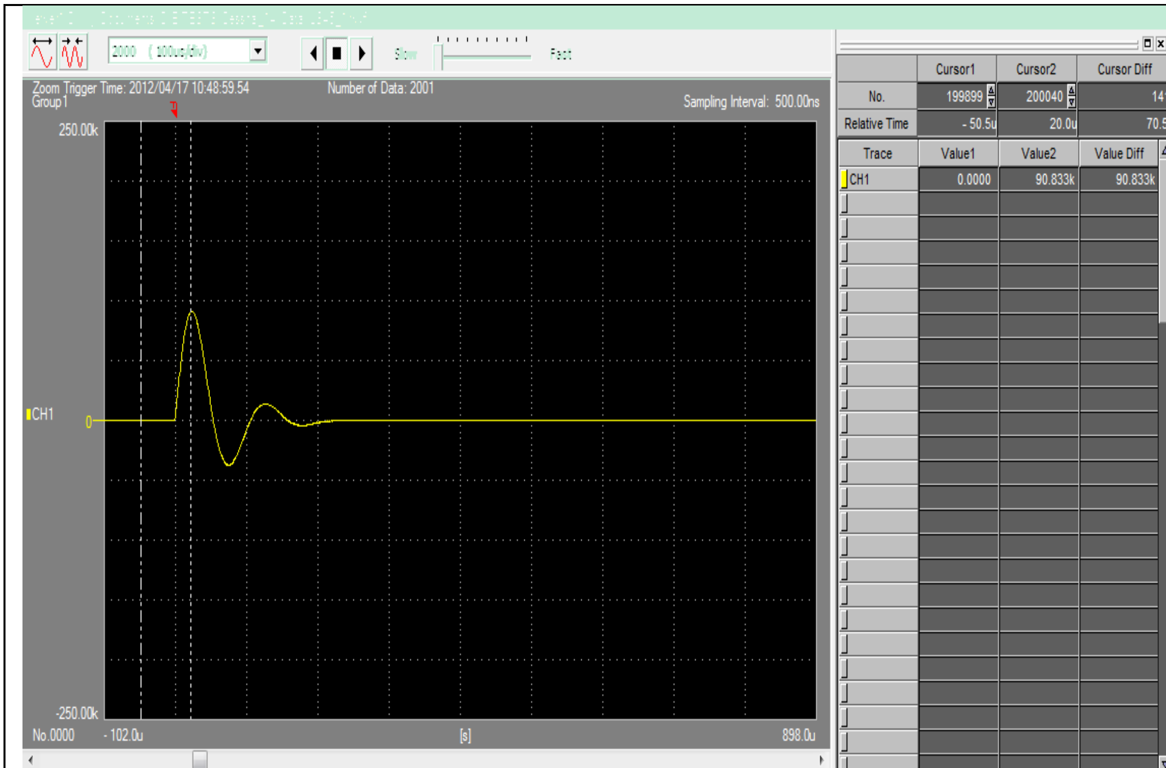


HIGH CURRENT – COMPONENT C*	Ip = 317 Amps	50 mS / Div

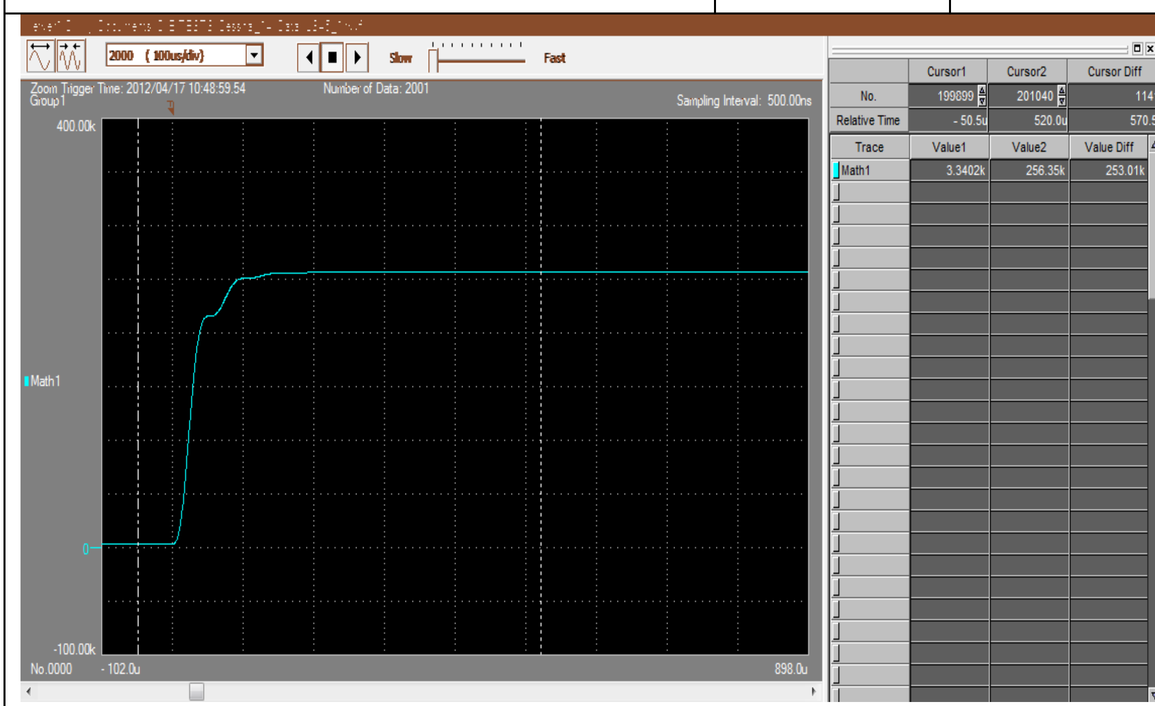


COMPONENT C* CHARGE TRANSFER	5.0 Coulombs

PANEL: LS-44

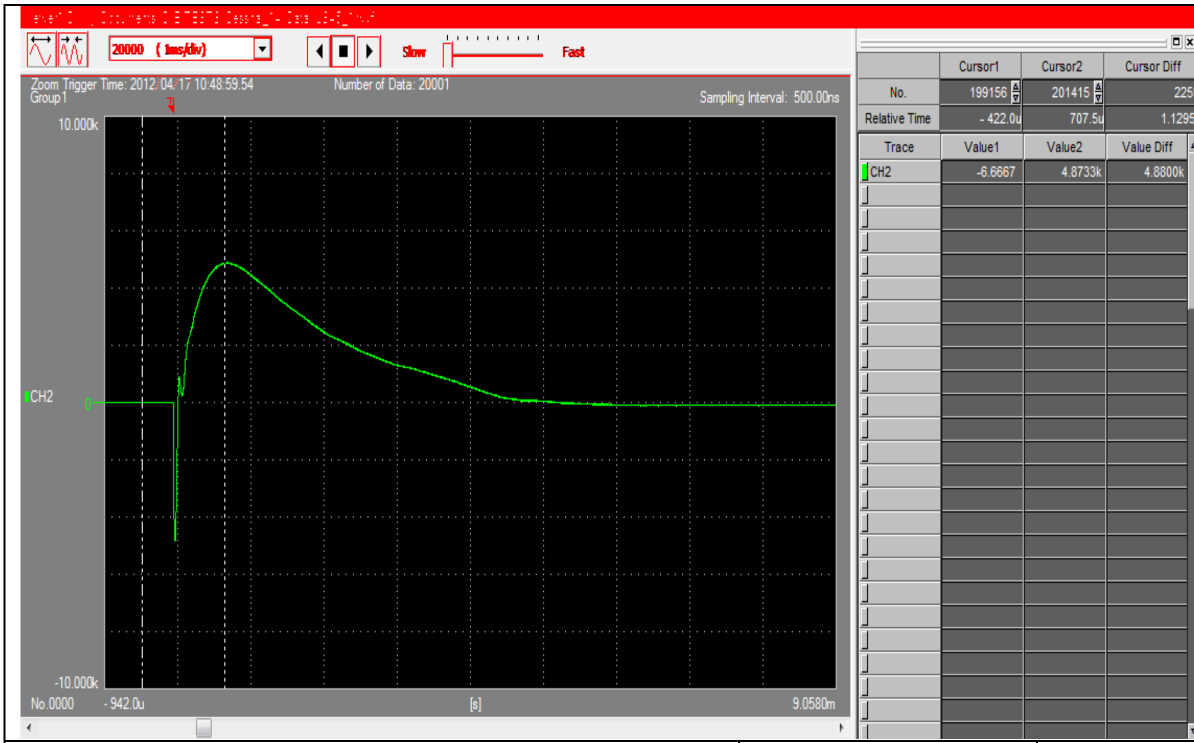


HIGH CURRENT – COMPONENT D	Ip = 90.8 KA	100 uS / Div

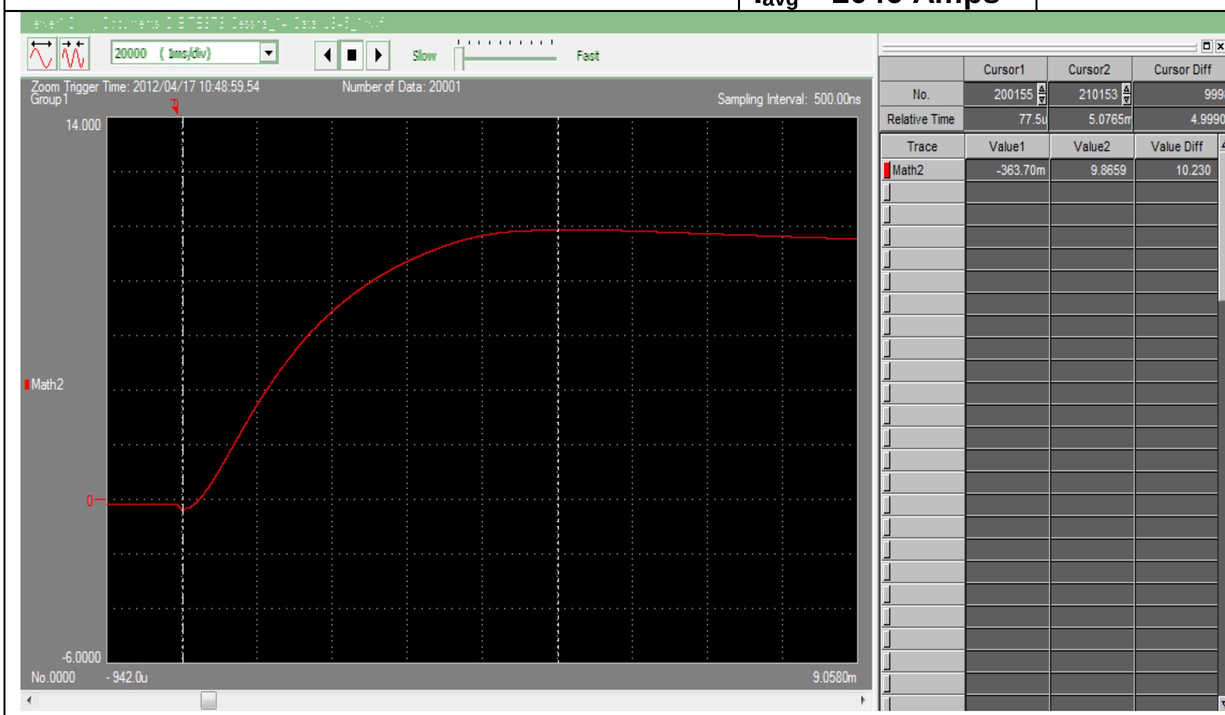


COMPONENT D ACTION INTEGRAL	AI = 253010 A^2-S

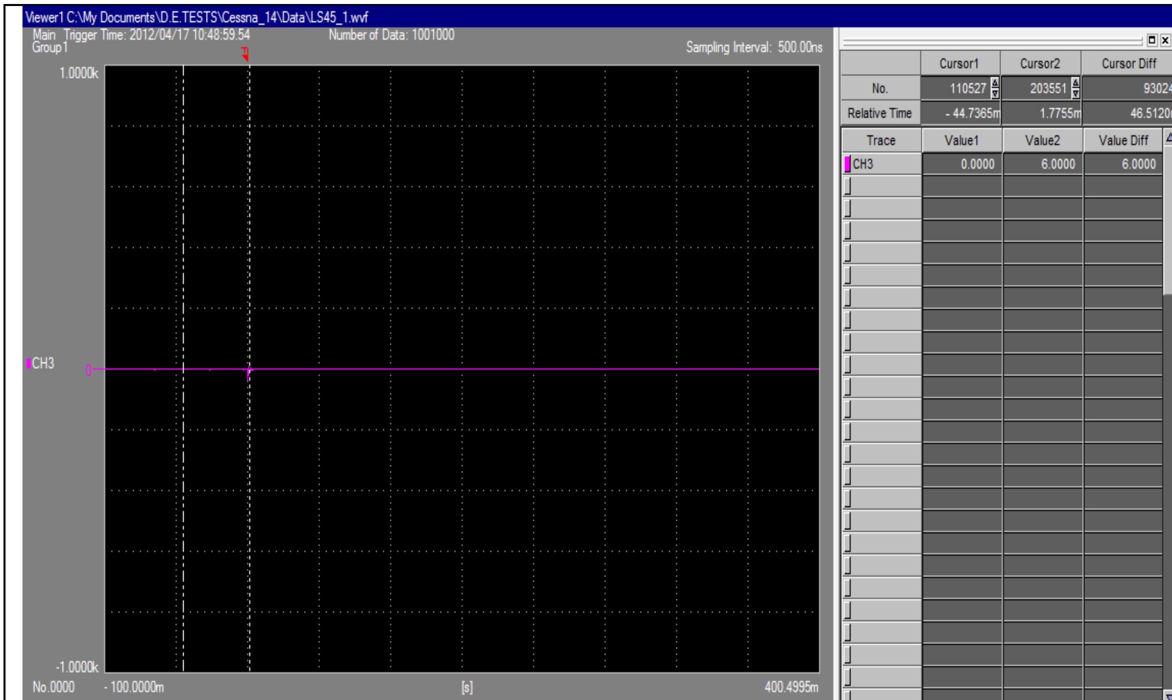
PANEL: LS-45



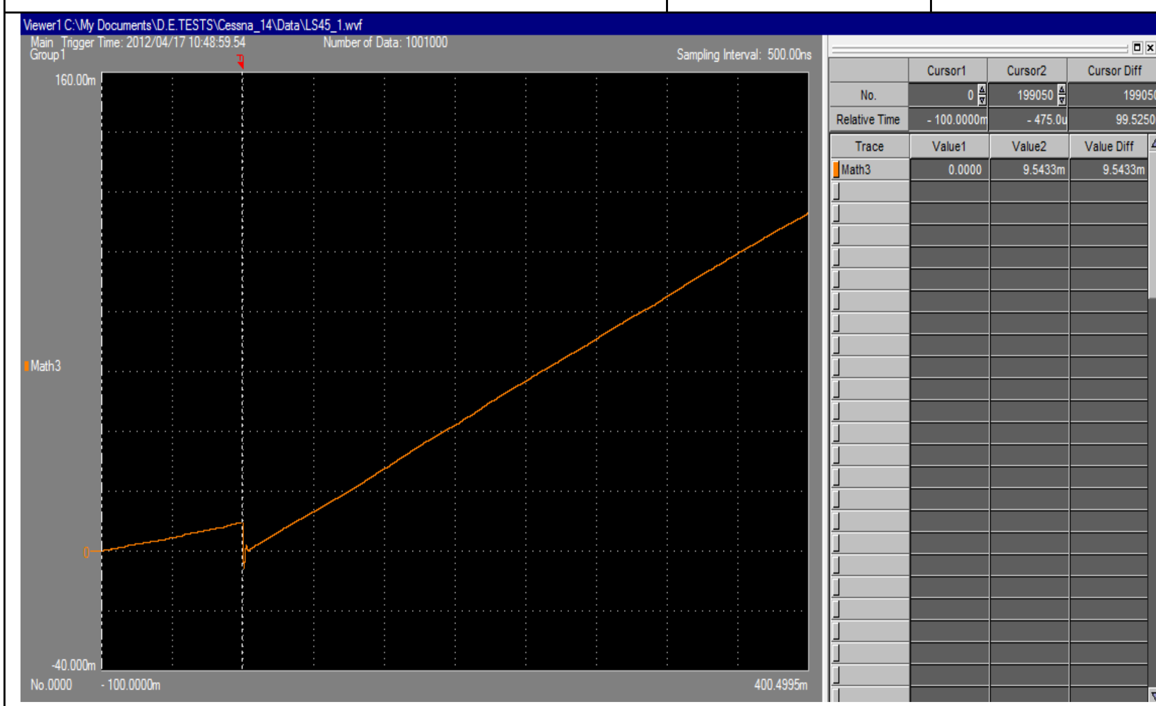
HIGH CURRENT – COMPONENT B	I_P = 4880 Amps I_{avg} = 2046 Amps	1 mS / Div



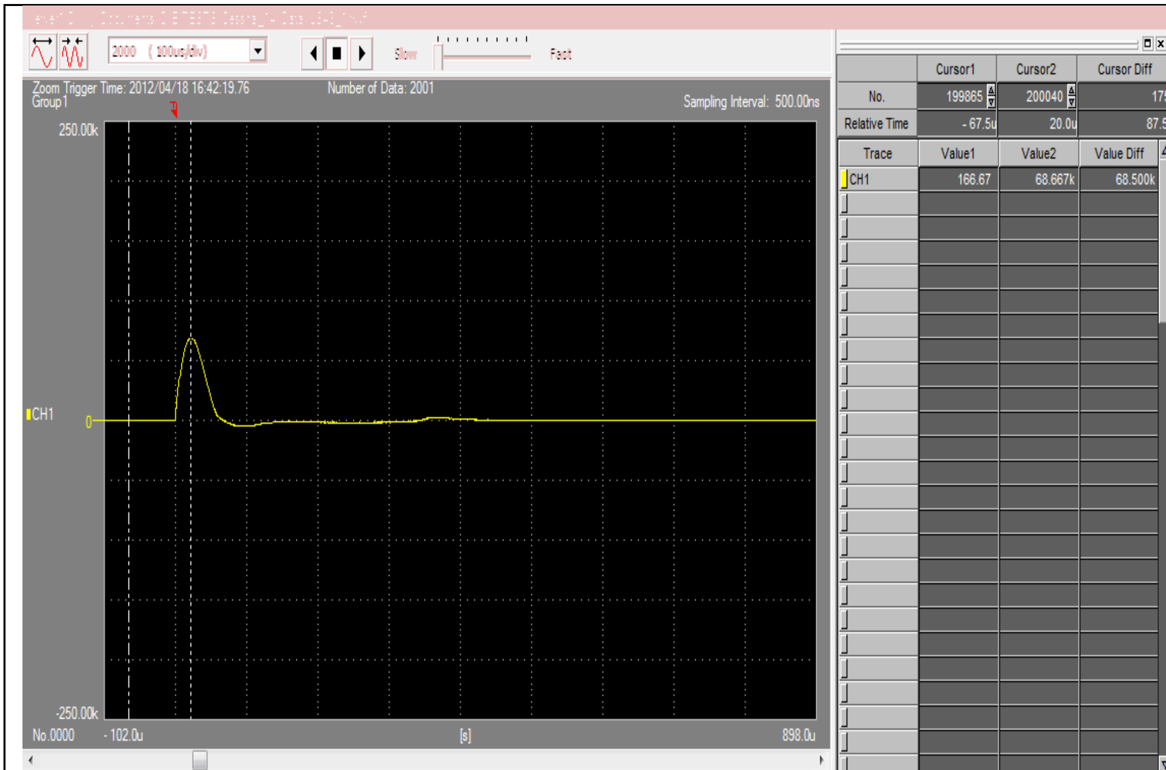
COMPONENT B CHARGE TRANSFER	10.230 Coulombs
PANEL: LS-45	



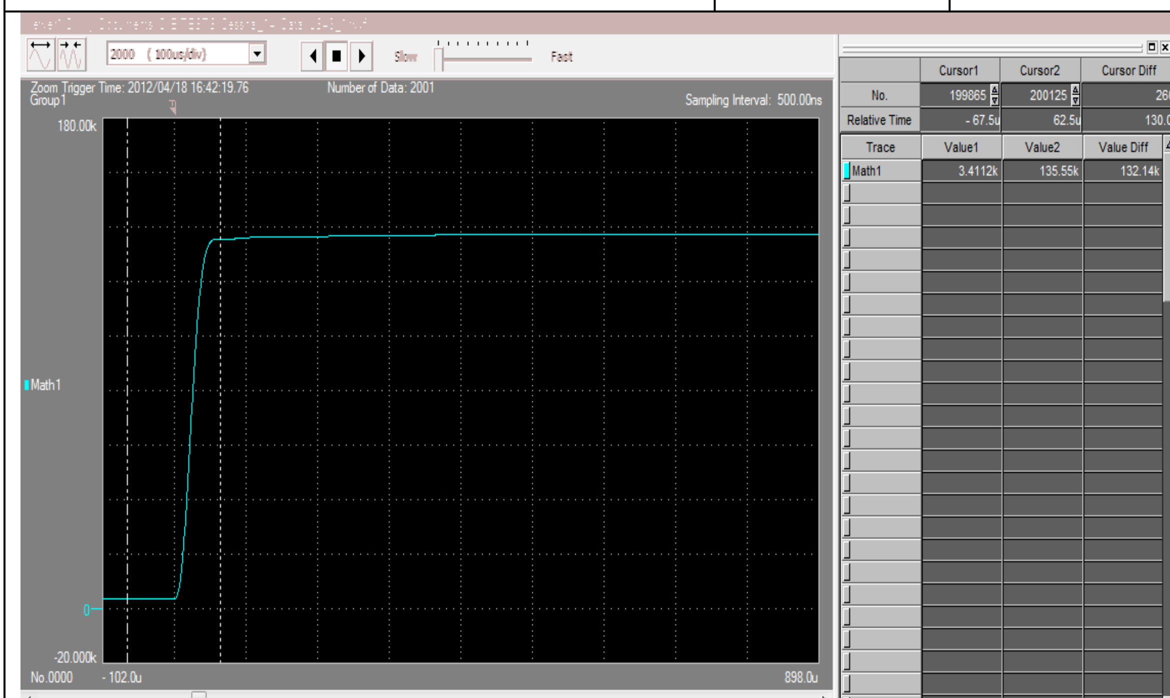
HIGH CURRENT – COMPONENT C*	Ip = 6 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	0.009 Coulombs
PANEL: LS-45	

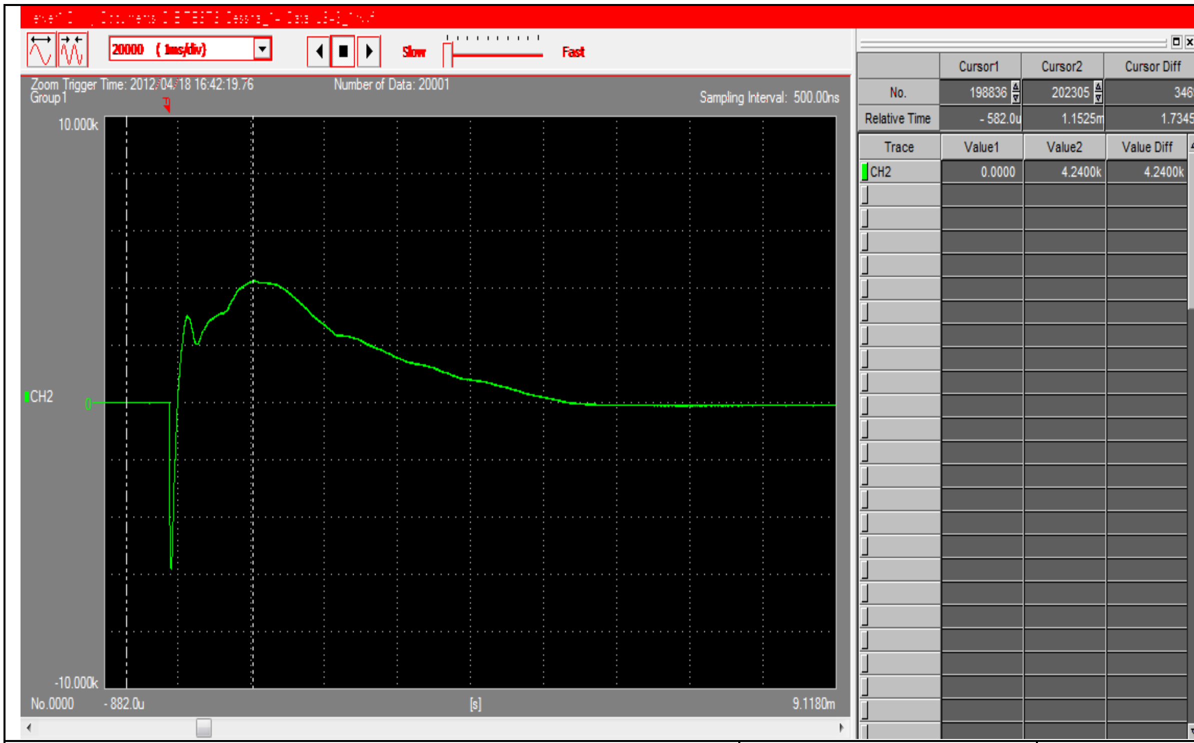


HIGH CURRENT – COMPONENT D	Ip = 68.5 KA	100 uS / Div

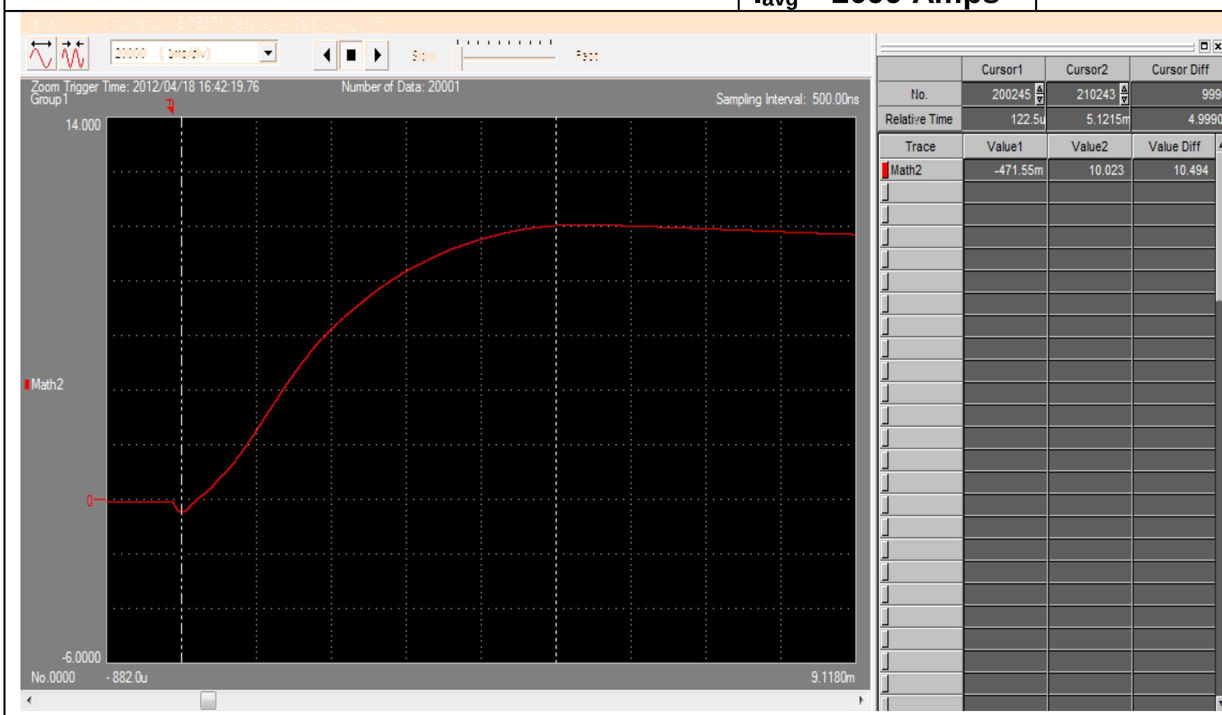


COMPONENT D ACTION INTEGRAL	AI = 132140 A^2-S

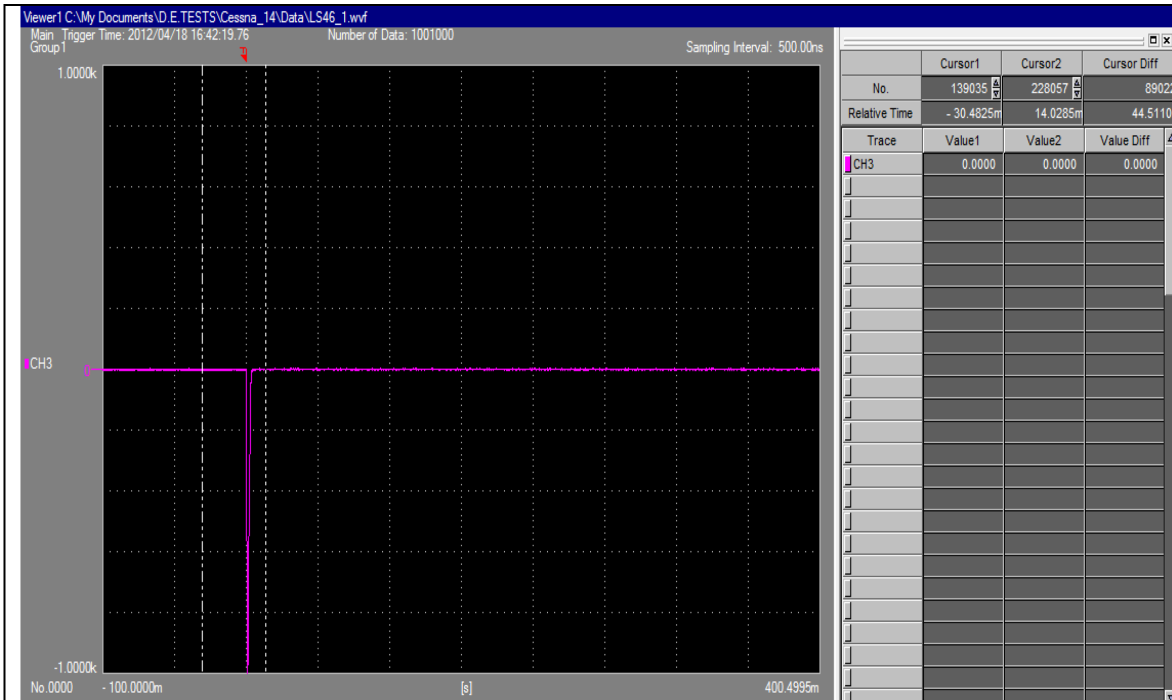
PANEL: LS-46



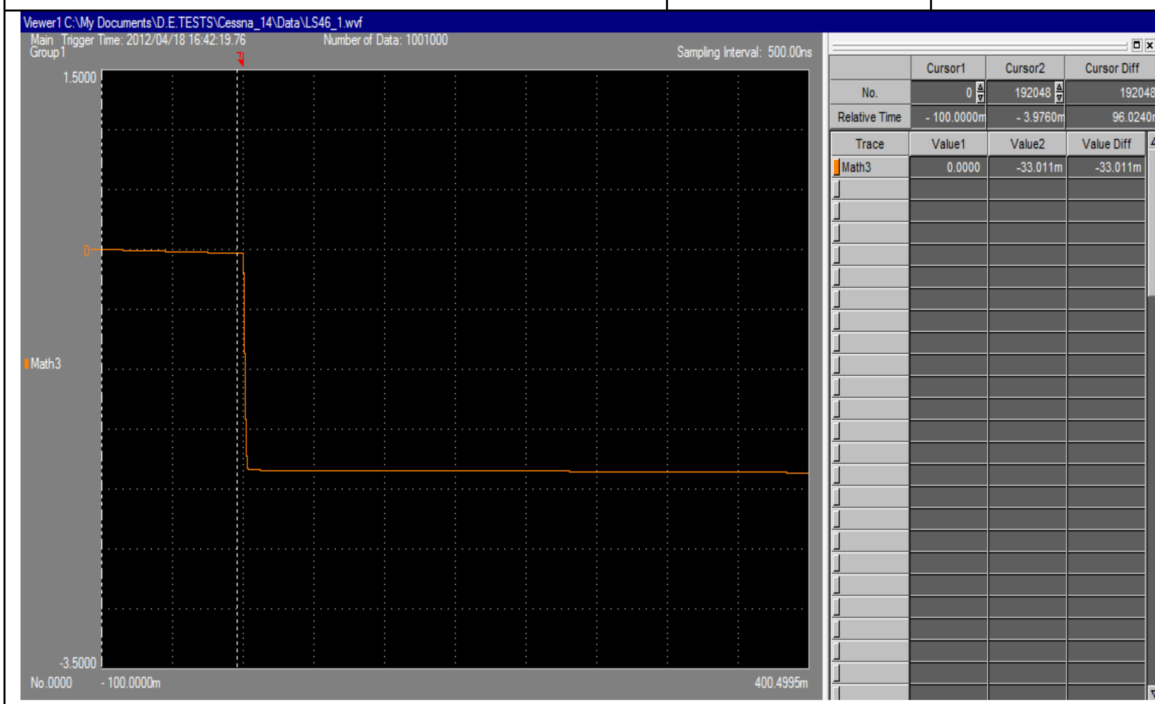
HIGH CURRENT – COMPONENT B	I_P = 4240 Amps I_{avg} = 2099 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.494 Coulombs
PANEL: LS-46	

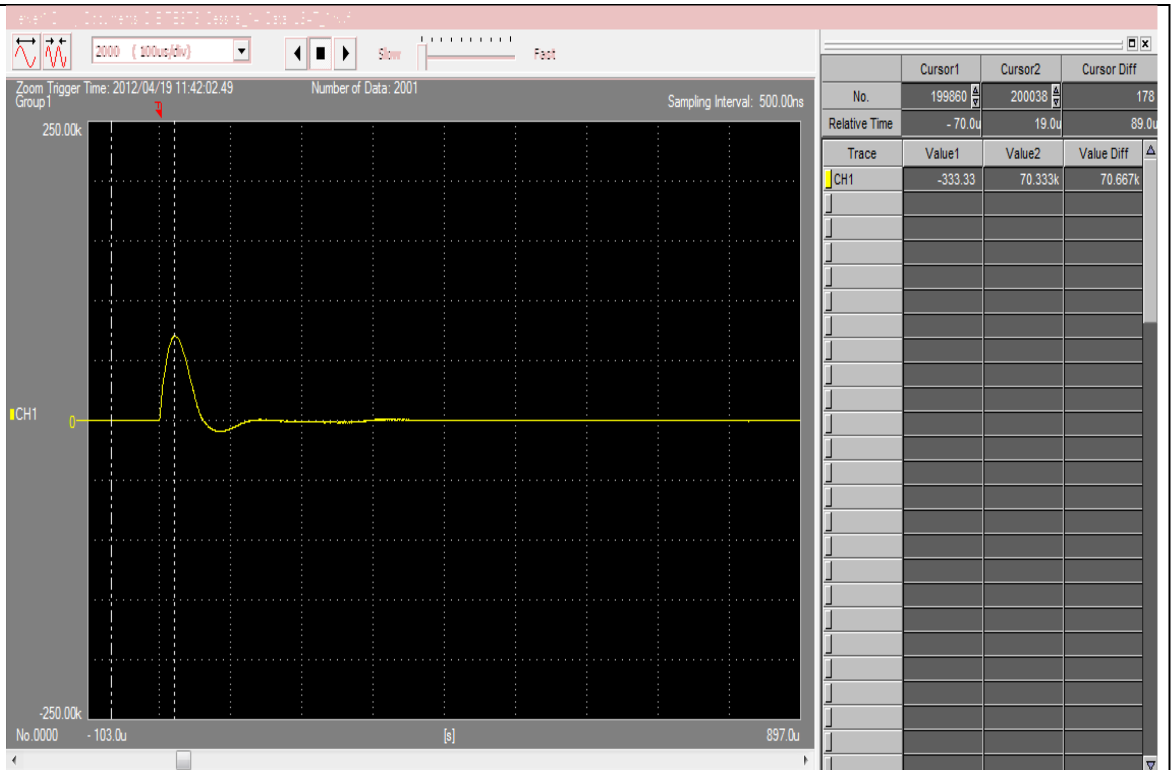


HIGH CURRENT – COMPONENT C*	Ip = 0 Amps	50 mS / Div

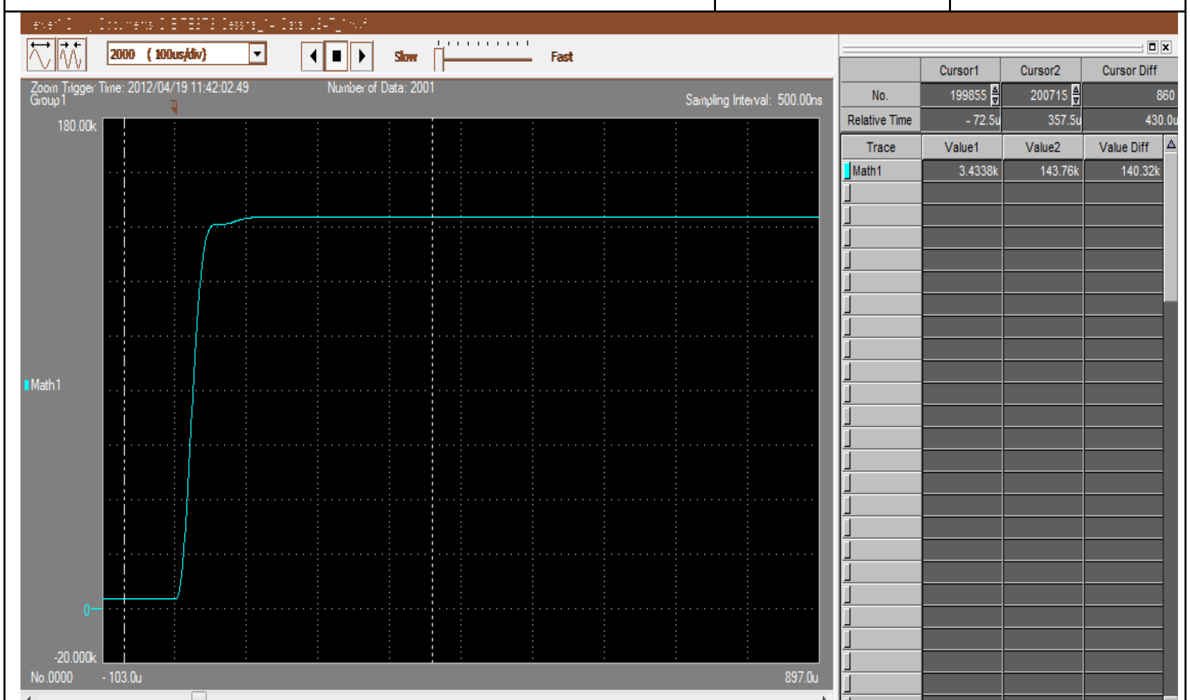


COMPONENT C* CHARGE TRANSFER	0 Coulombs

PANEL: LS-46

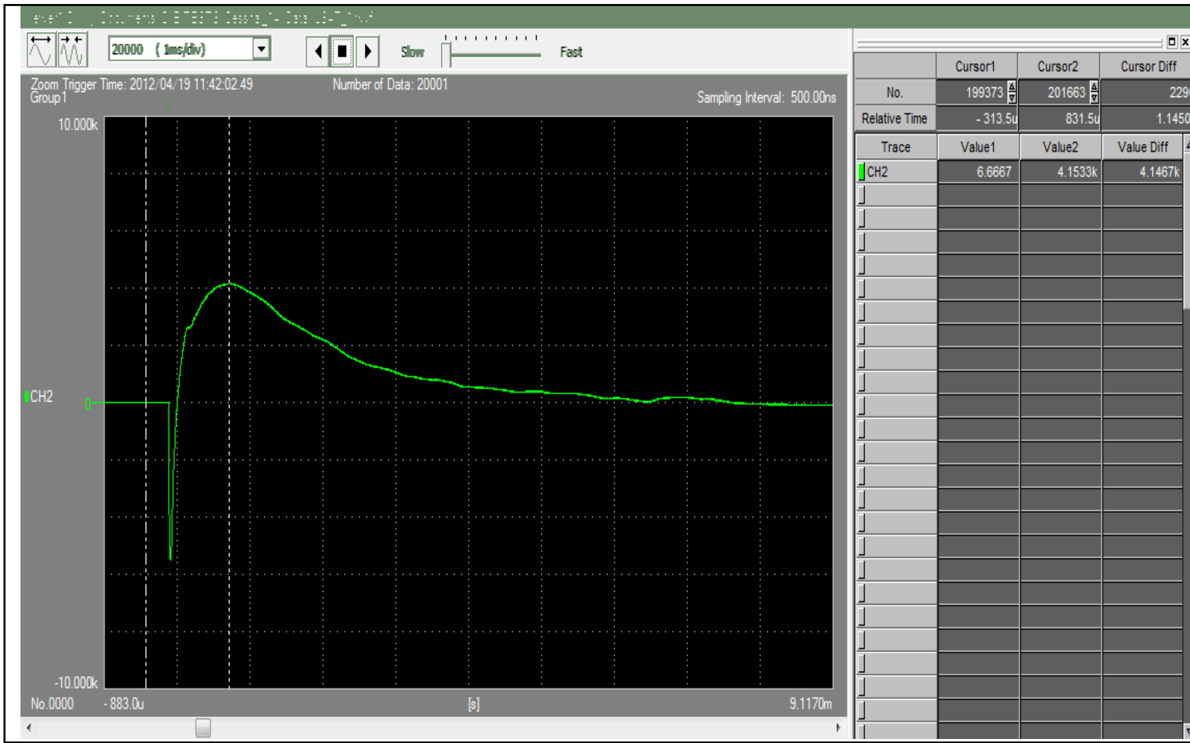


HIGH CURRENT – COMPONENT D	Ip = 70.7 KA	100 uS / Div

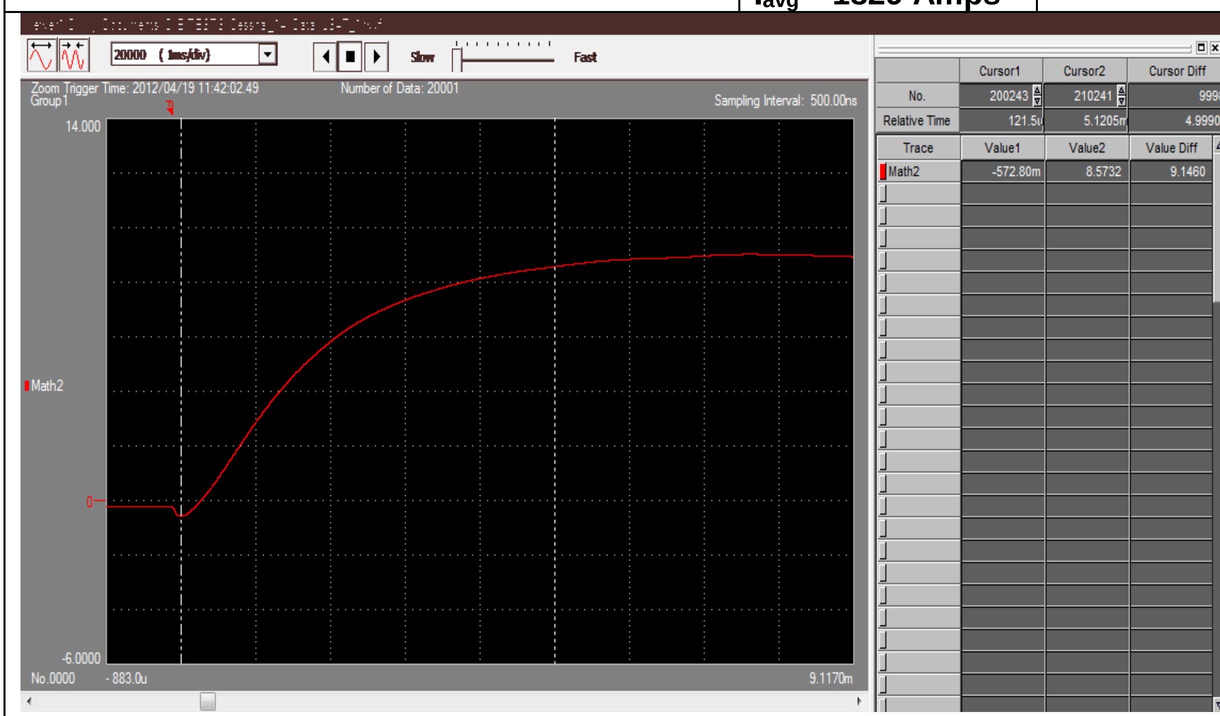


COMPONENT D ACTION INTEGRAL	AI = 140320 A^2-S

PANEL: LS-47

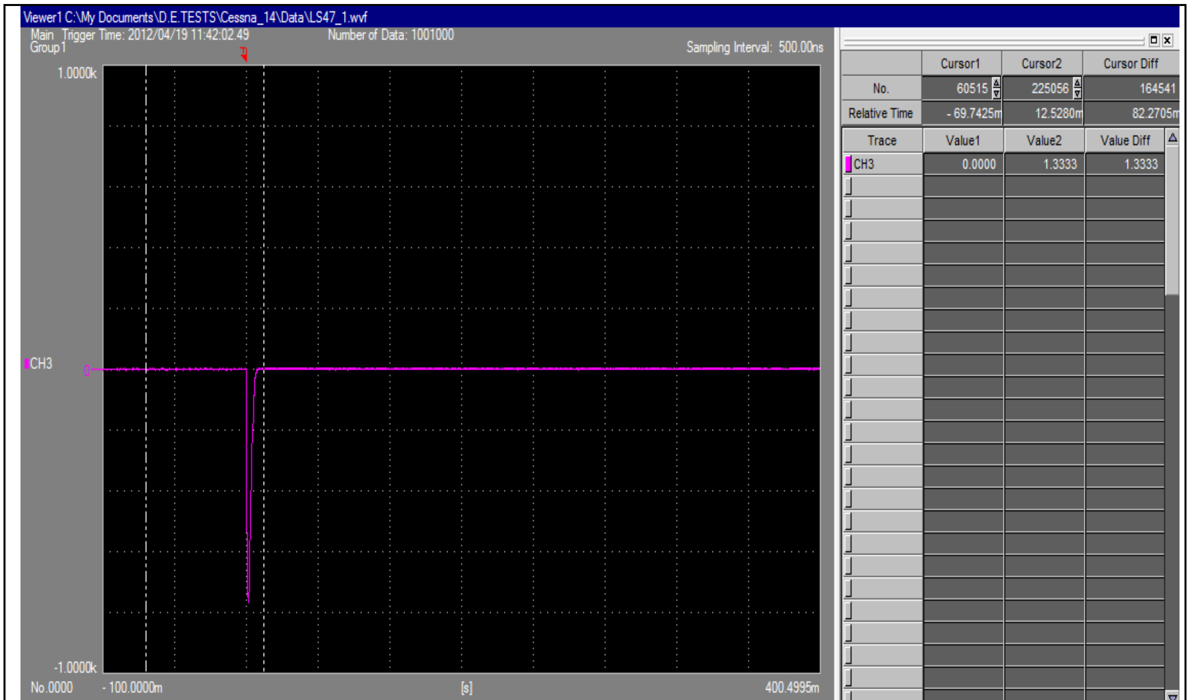


HIGH CURRENT – COMPONENT B	I_P = 4147 Amps I_{avg} = 1829 Amps	1 mS / Div

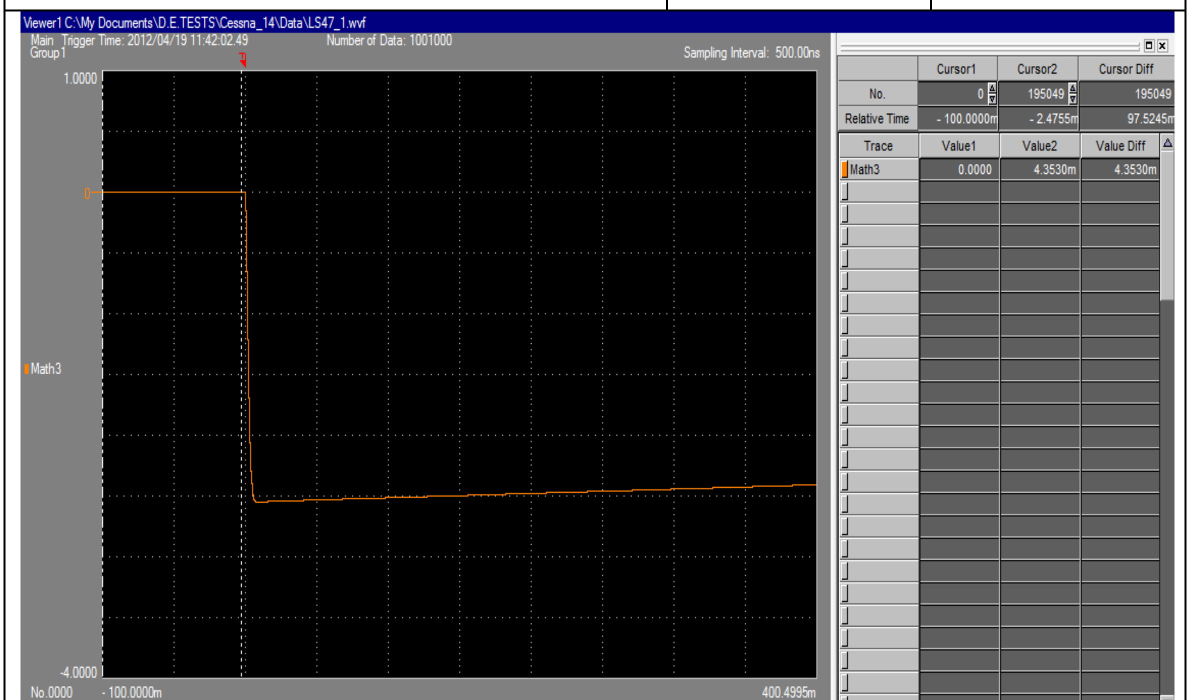


COMPONENT B CHARGE TRANSFER	9.146 Coulombs

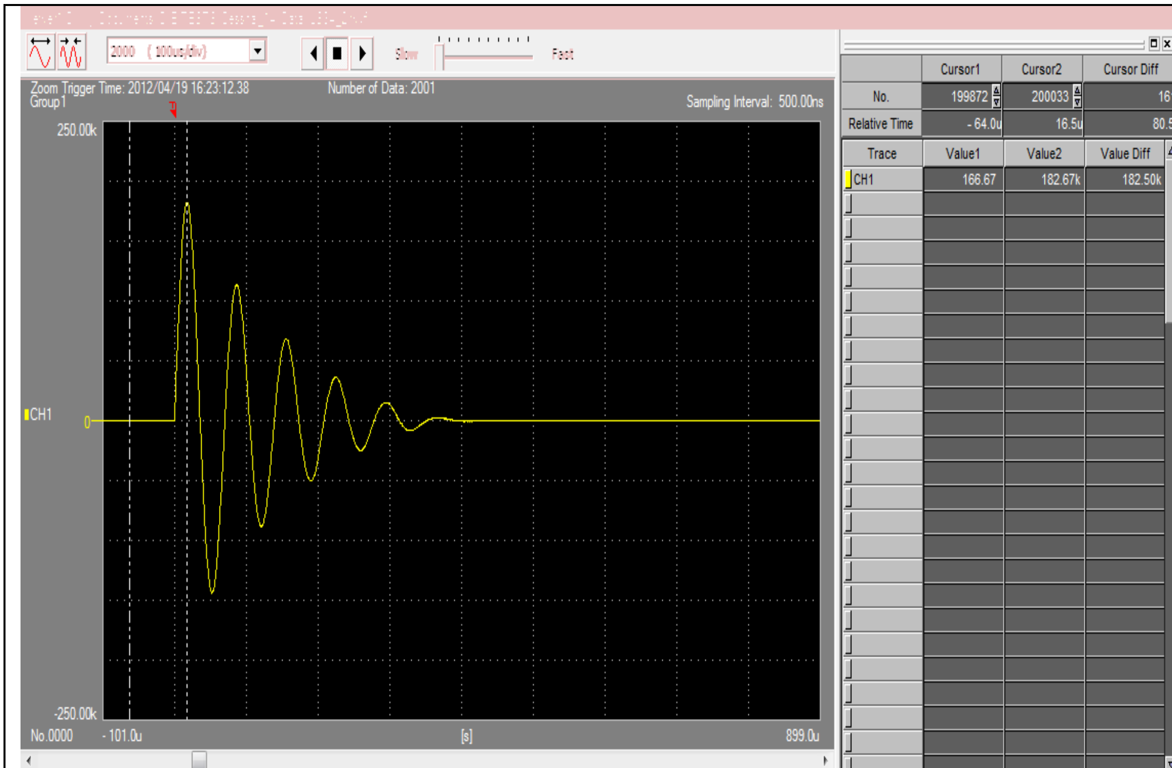
PANEL: LS-47



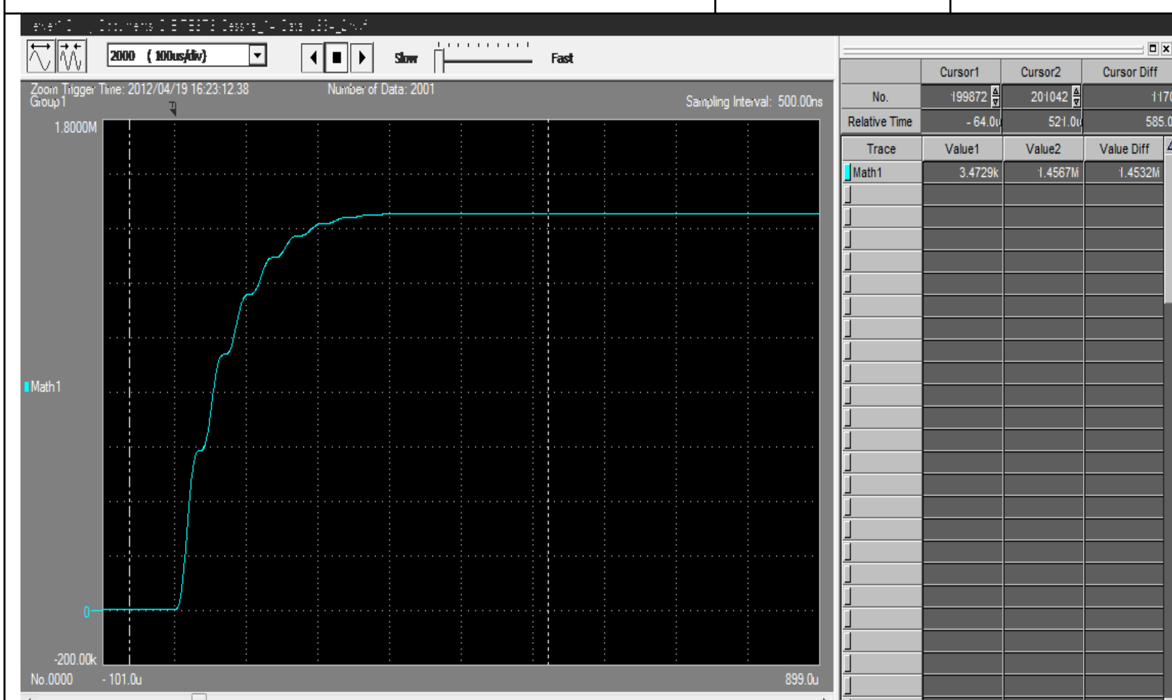
HIGH CURRENT – COMPONENT C*	Ip = 1.3 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	0.004 Coulombs
PANEL: LS-47	

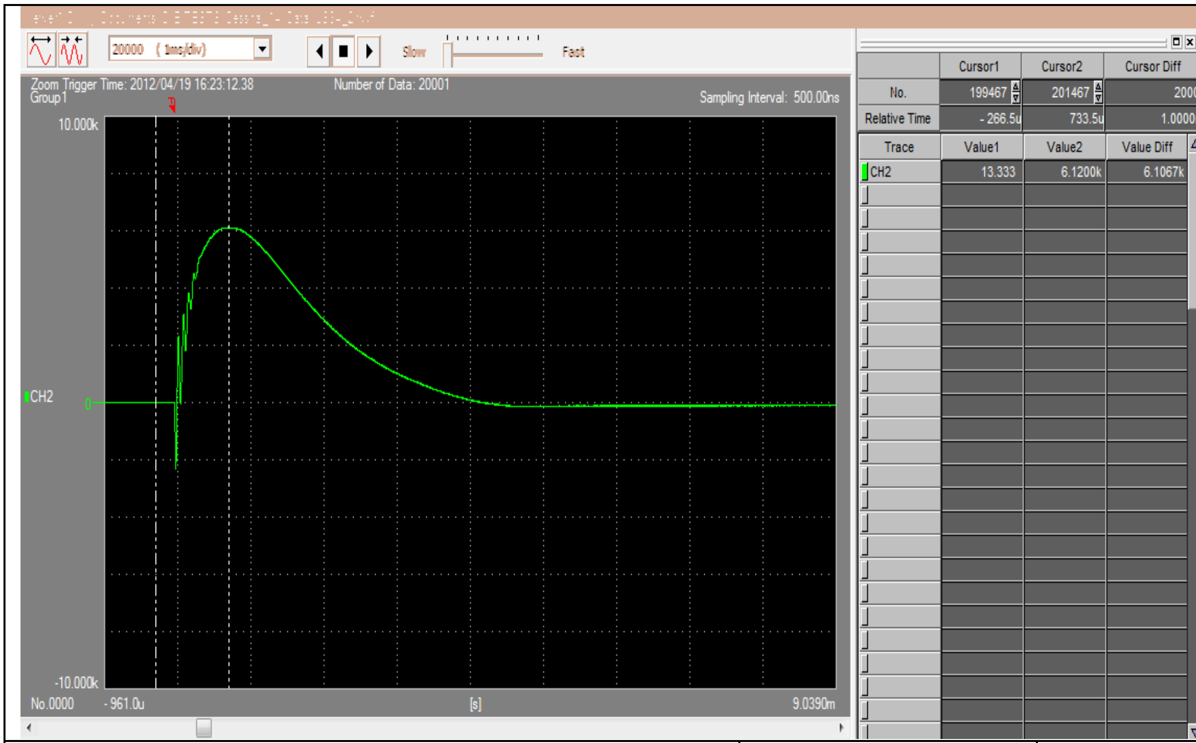


HIGH CURRENT – COMPONENT A	Ip = 182.5 KA	100 uS / Div

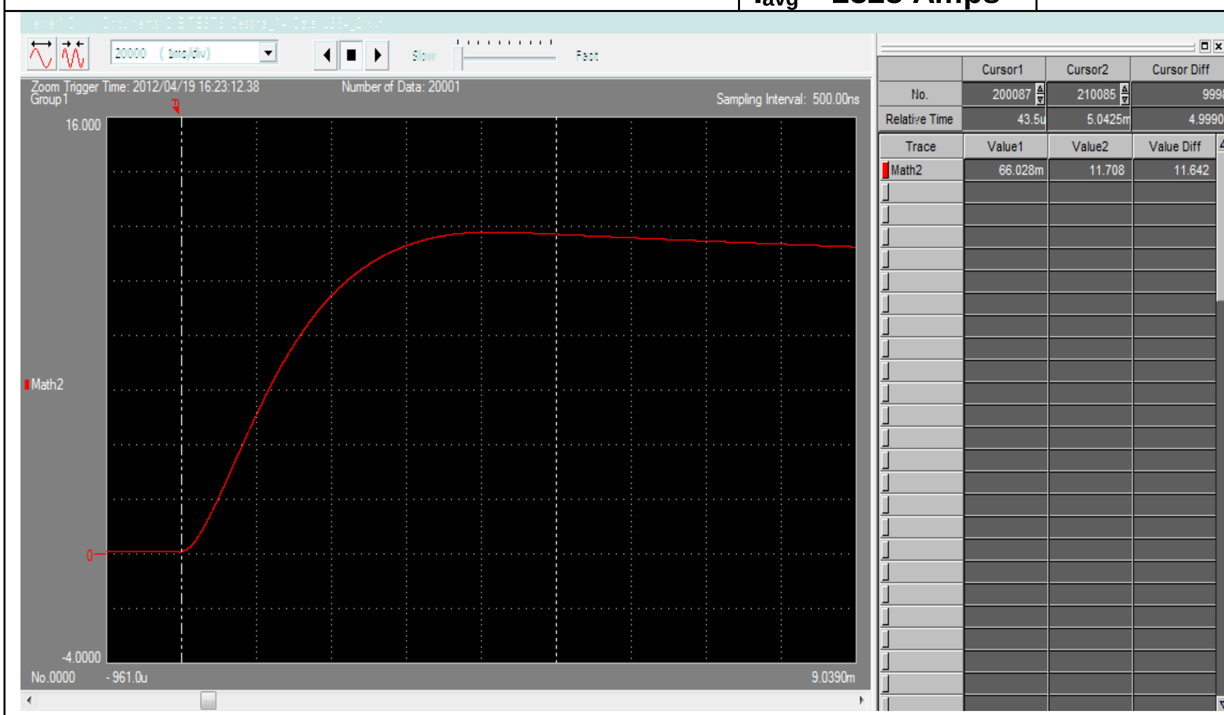


COMPONENT A ACTION INTEGRAL	AI = 1.4532E6 A^2-S

PANEL: LS-34

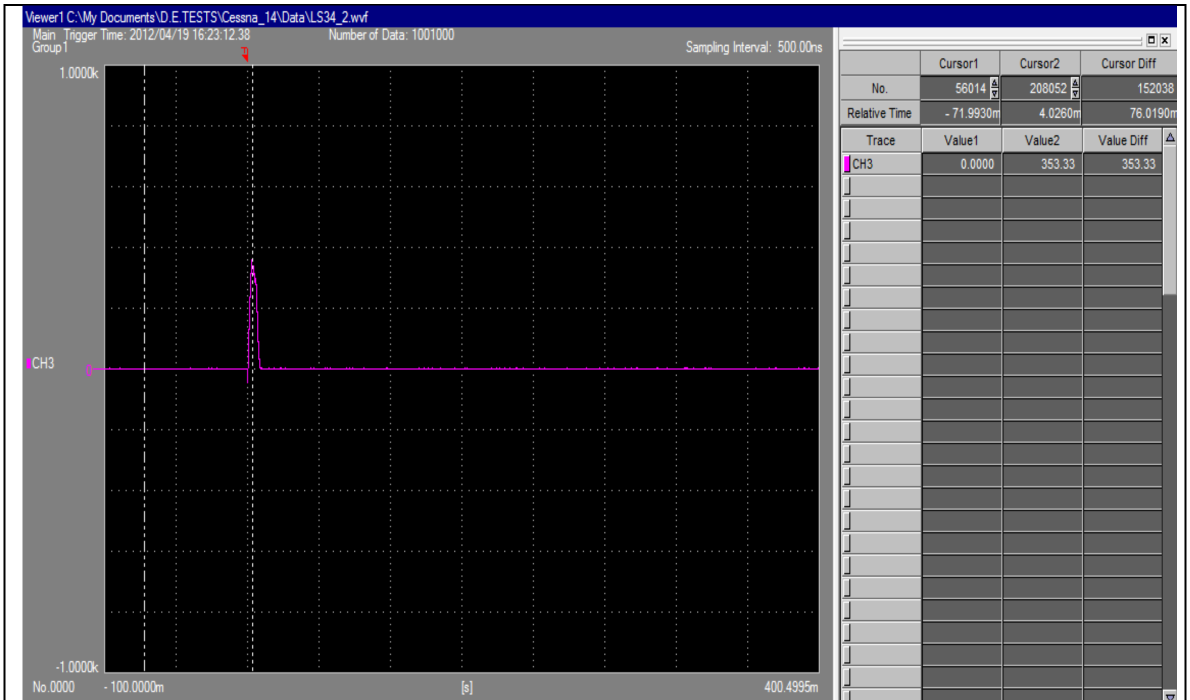


HIGH CURRENT – COMPONENT B	I_P = 6107 Amps I_{avg} = 2328 Amps	1 mS / Div

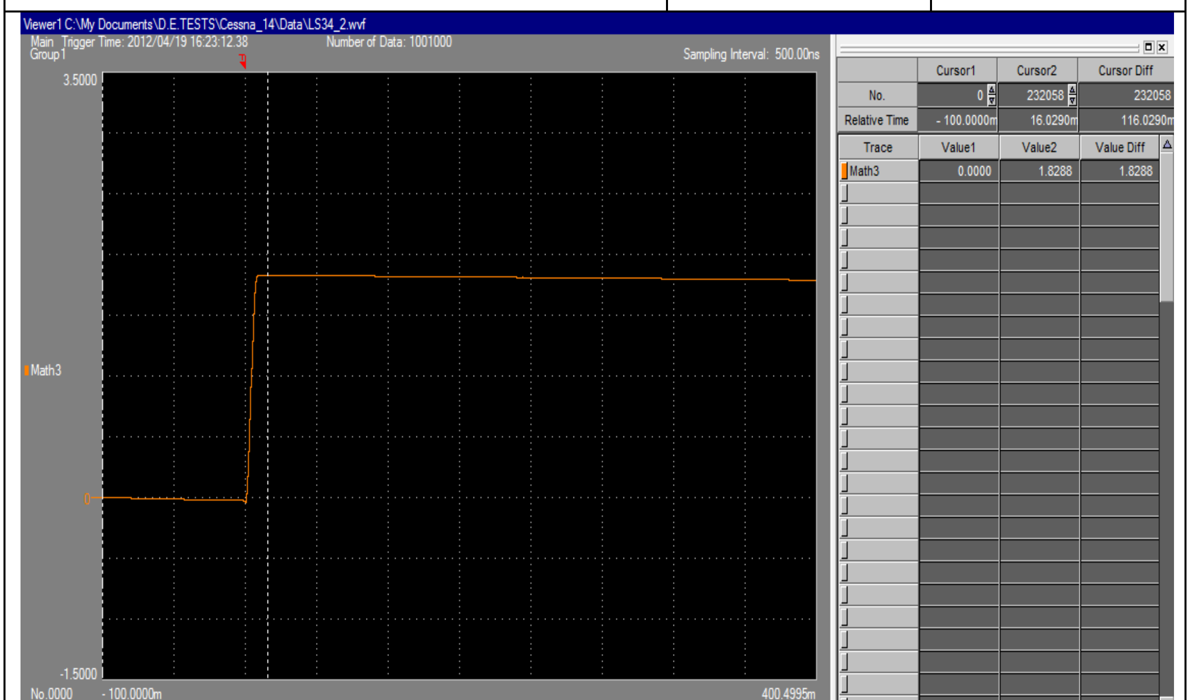


COMPONENT B CHARGE TRANSFER	11.642 Coulombs

PANEL: LS-34

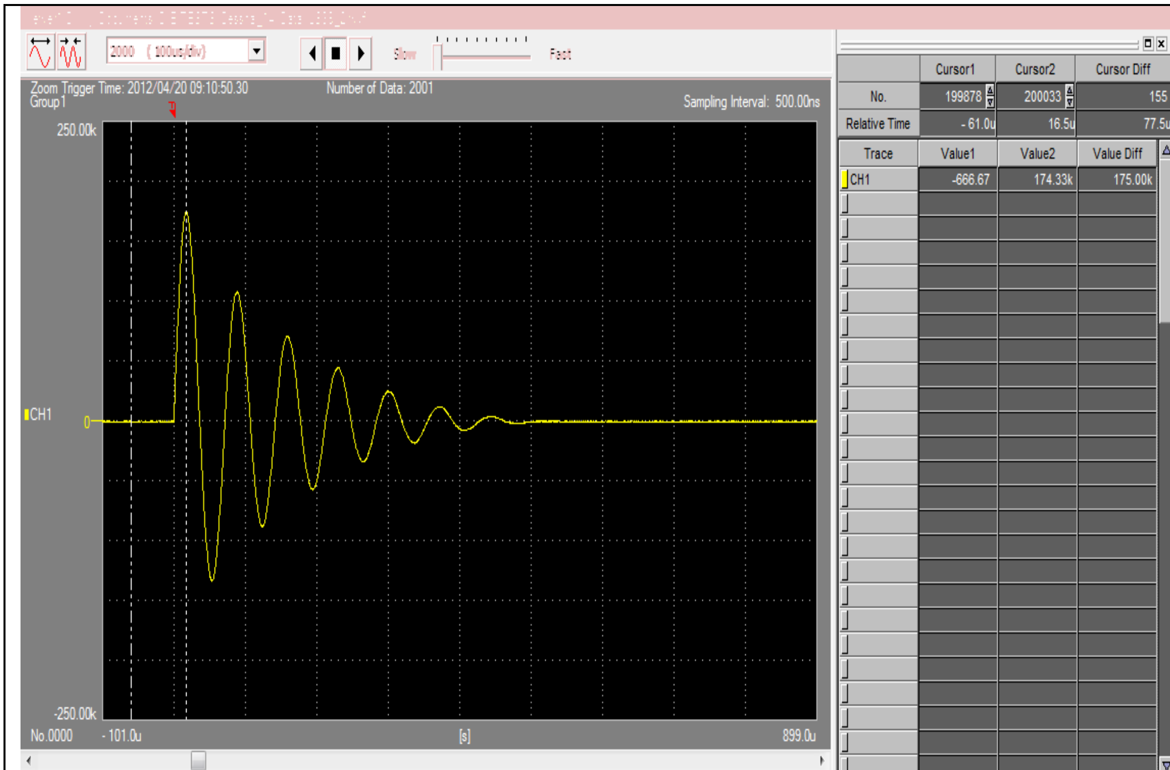


HIGH CURRENT – COMPONENT C*	Ip = 353 Amps	50 mS / Div

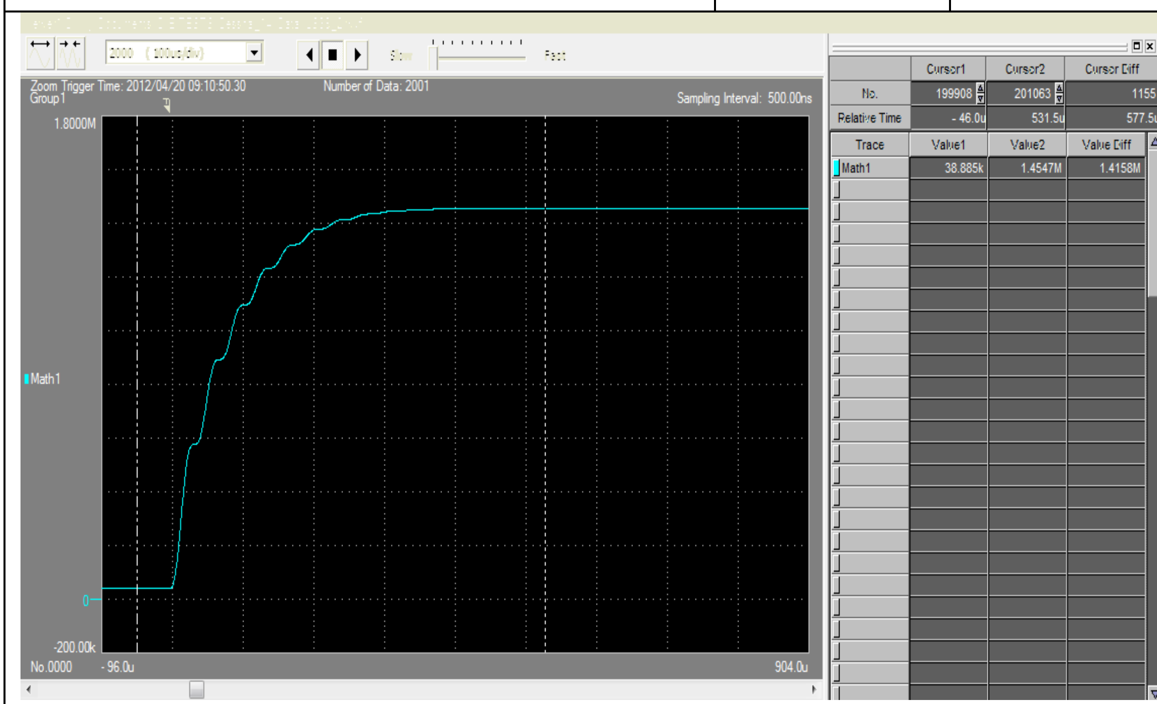


COMPONENT C* CHARGE TRANSFER	1.8 Coulombs

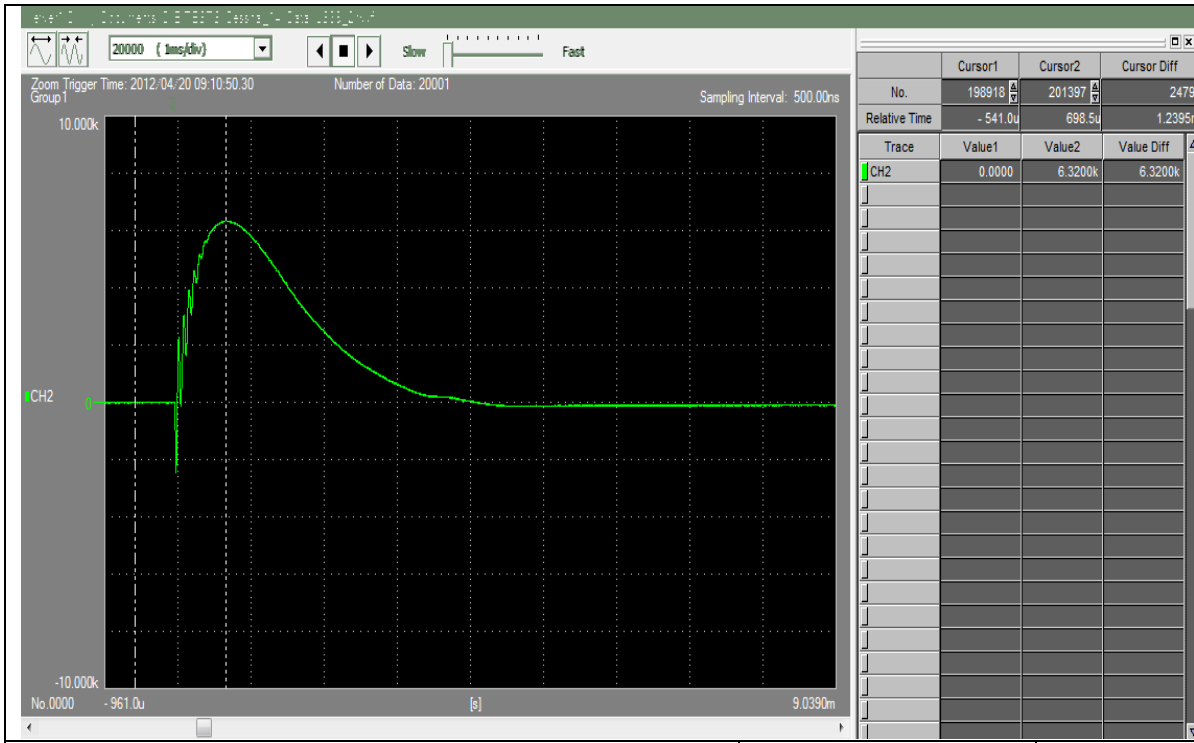
PANEL: LS-34



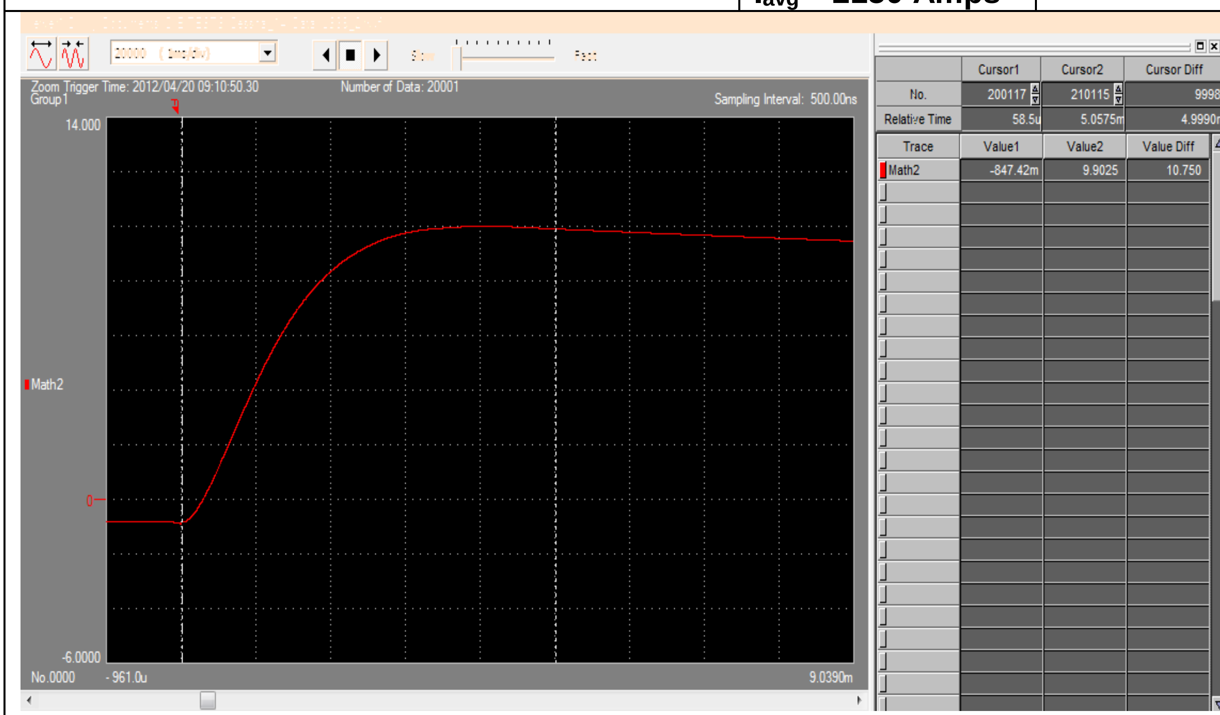
HIGH CURRENT – COMPONENT A	Ip = 175.0 KA	100 uS / Div



COMPONENT A ACTION INTEGRAL	AI = 1.4158E6 A^2-S
PANEL: LS-39	

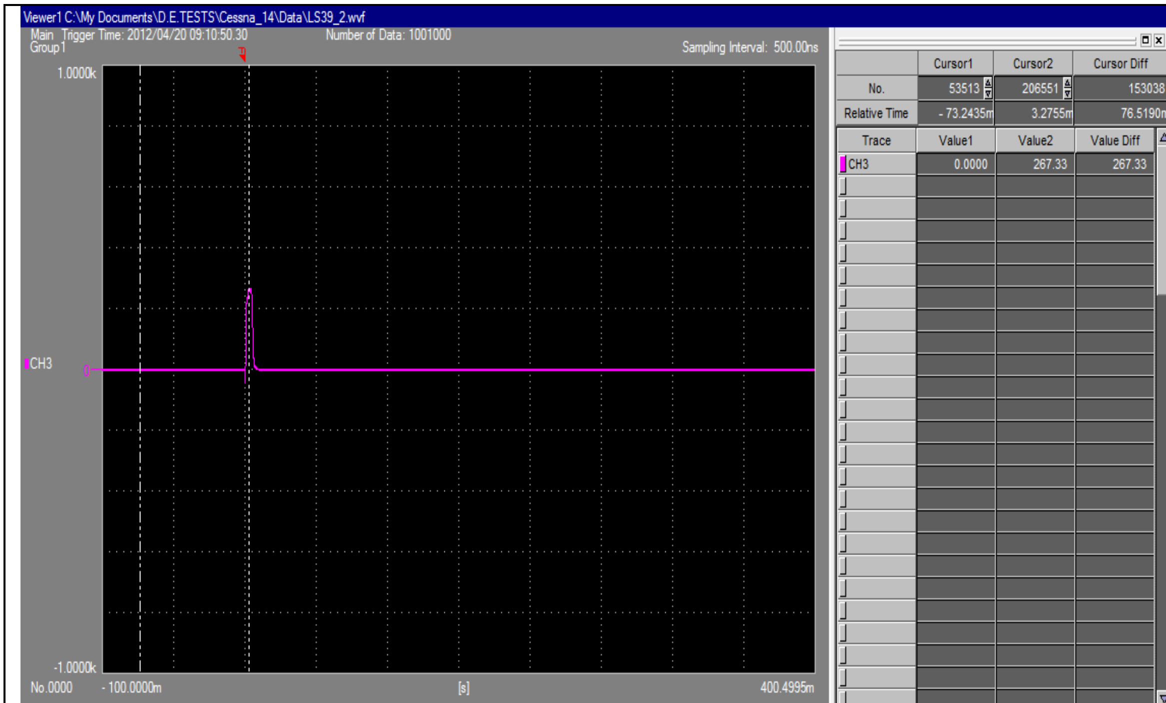


HIGH CURRENT – COMPONENT B	I_P = 6320 Amps I_{avg} = 2150 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.750 Coulombs

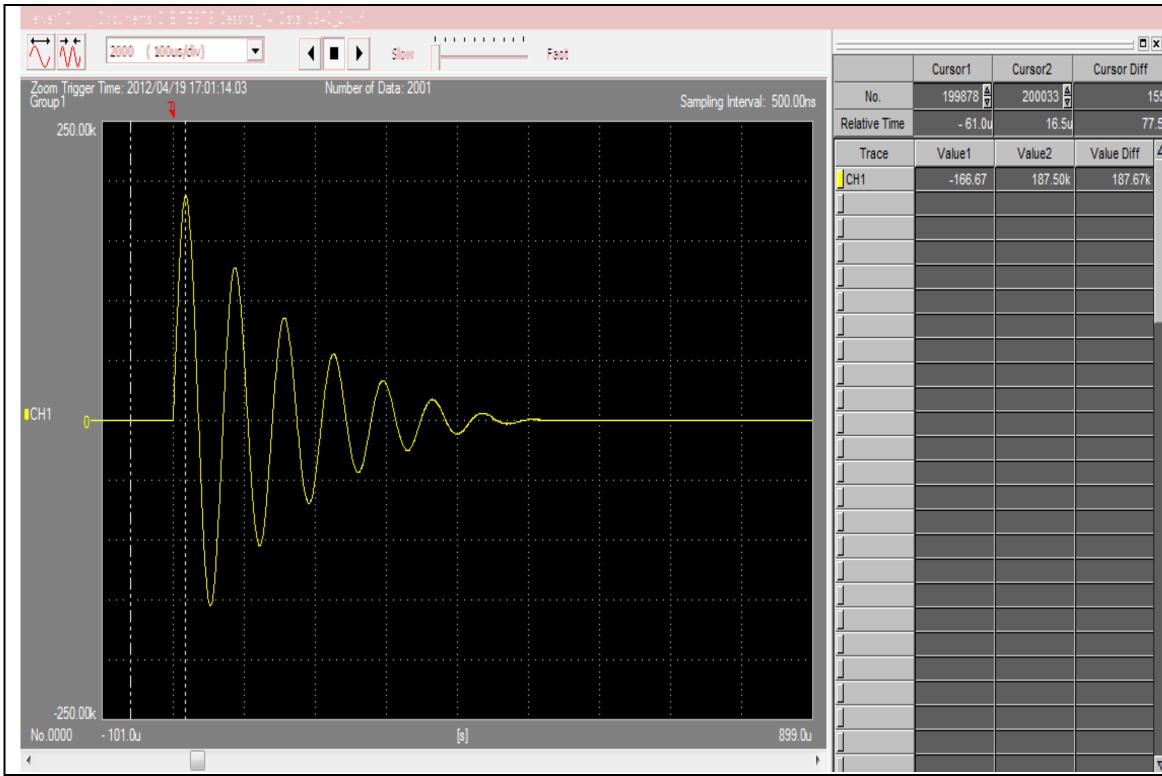
PANEL: LS-39



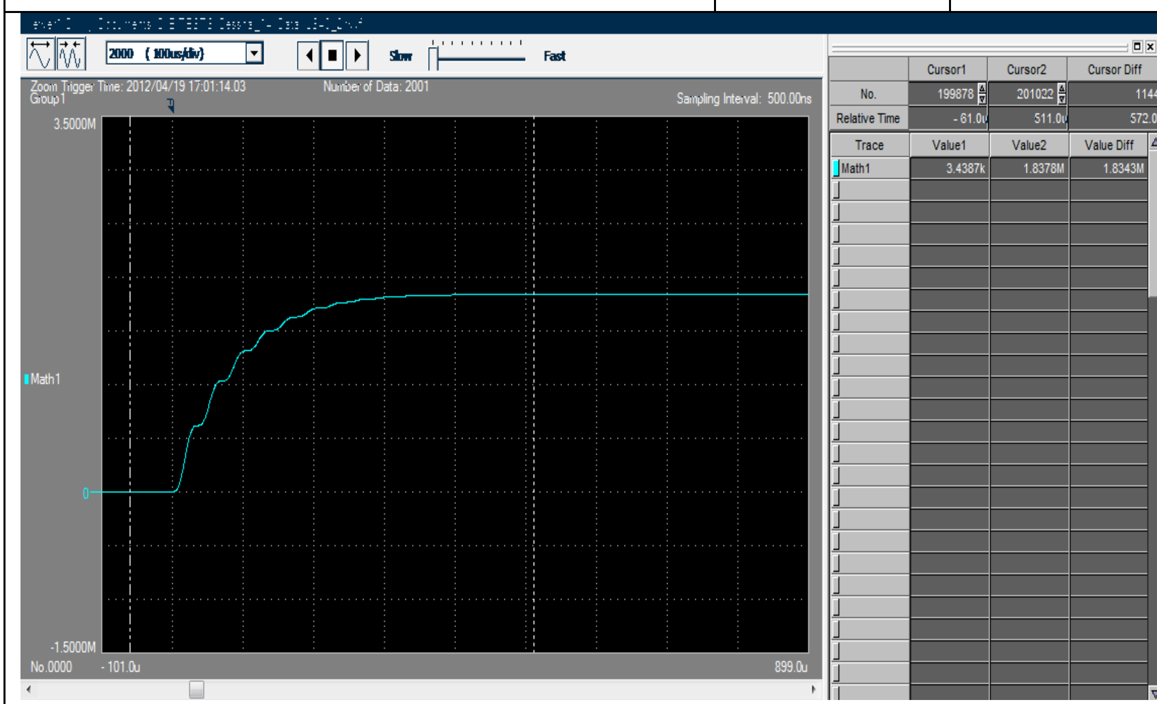
HIGH CURRENT – COMPONENT C*	Ip = 267 Amps	50 mS / Div

COMPONENT C* CHARGE TRANSFER	1.1 Coulombs

PANEL: LS-39

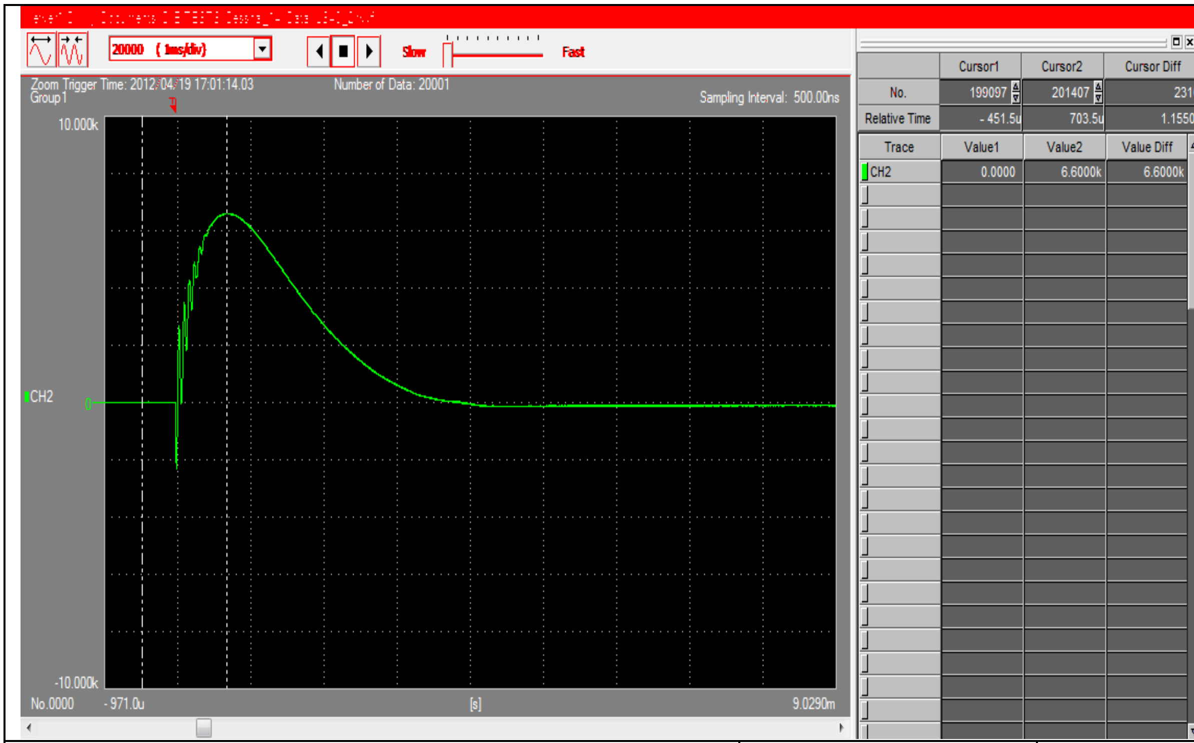


HIGH CURRENT – COMPONENT A	Ip = 187.7 KA	100 uS / Div

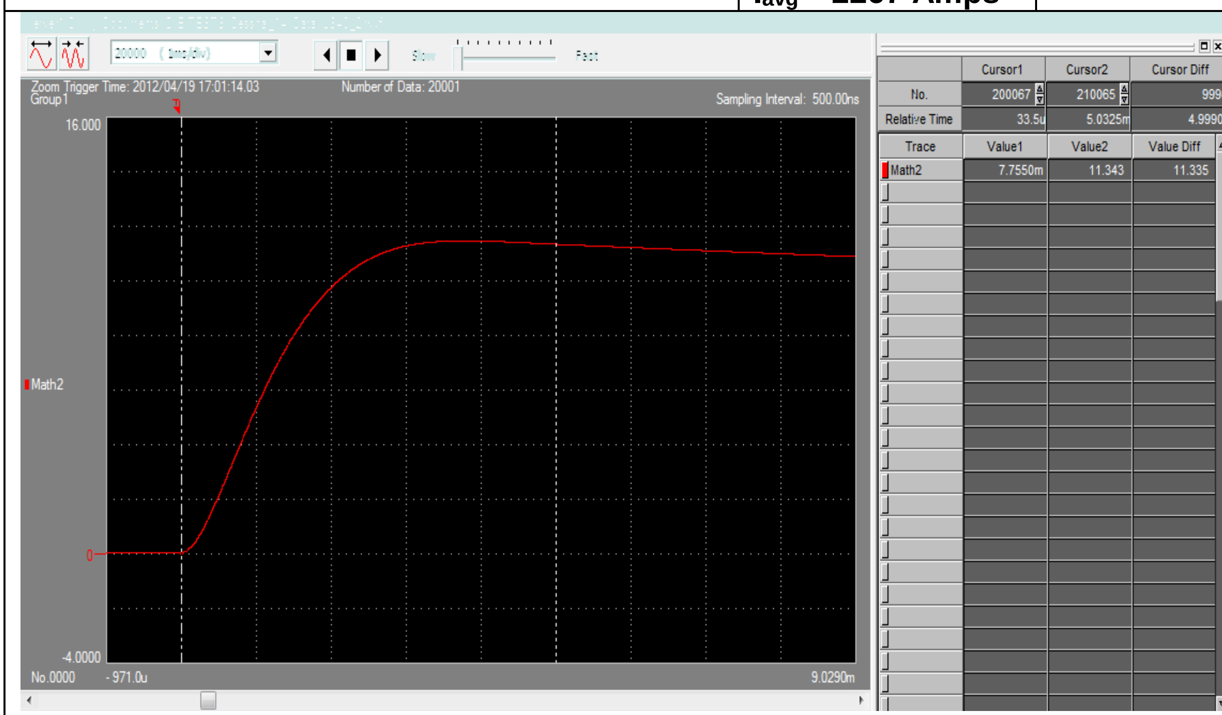


COMPONENT A ACTION INTEGRAL	AI = 1.8343E6 A^2-S

PANEL: LS-40

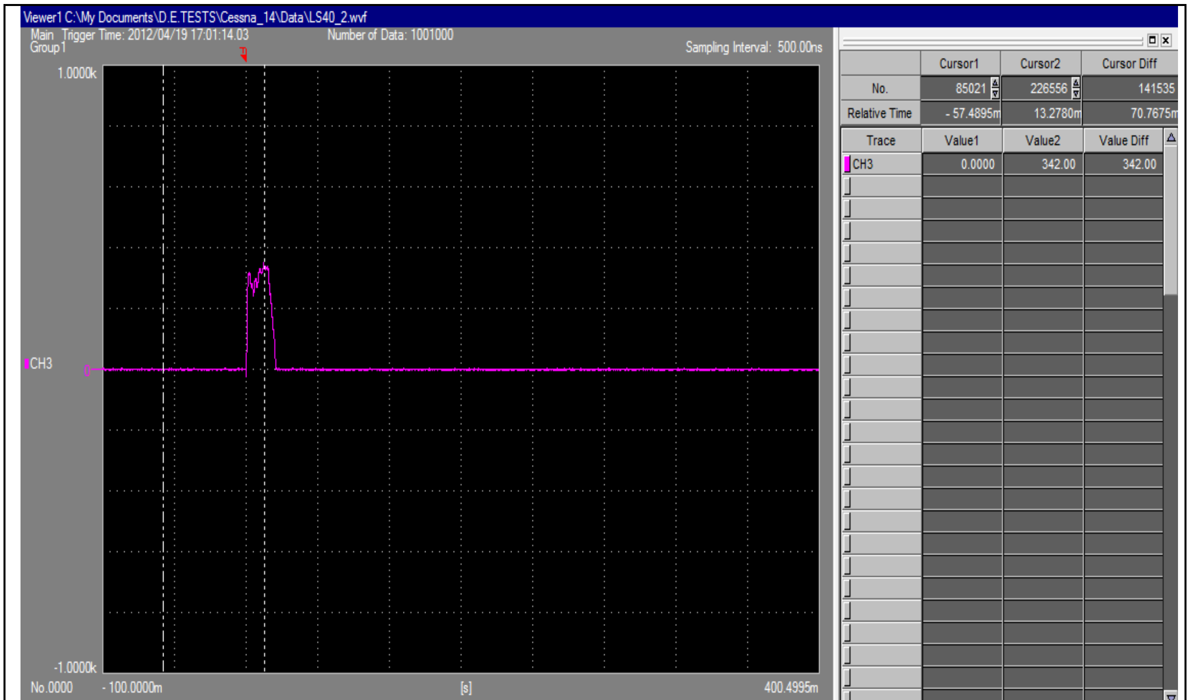


HIGH CURRENT – COMPONENT B	I_P = 6600 Amps I_{avg} = 2267 Amps	1 mS / Div

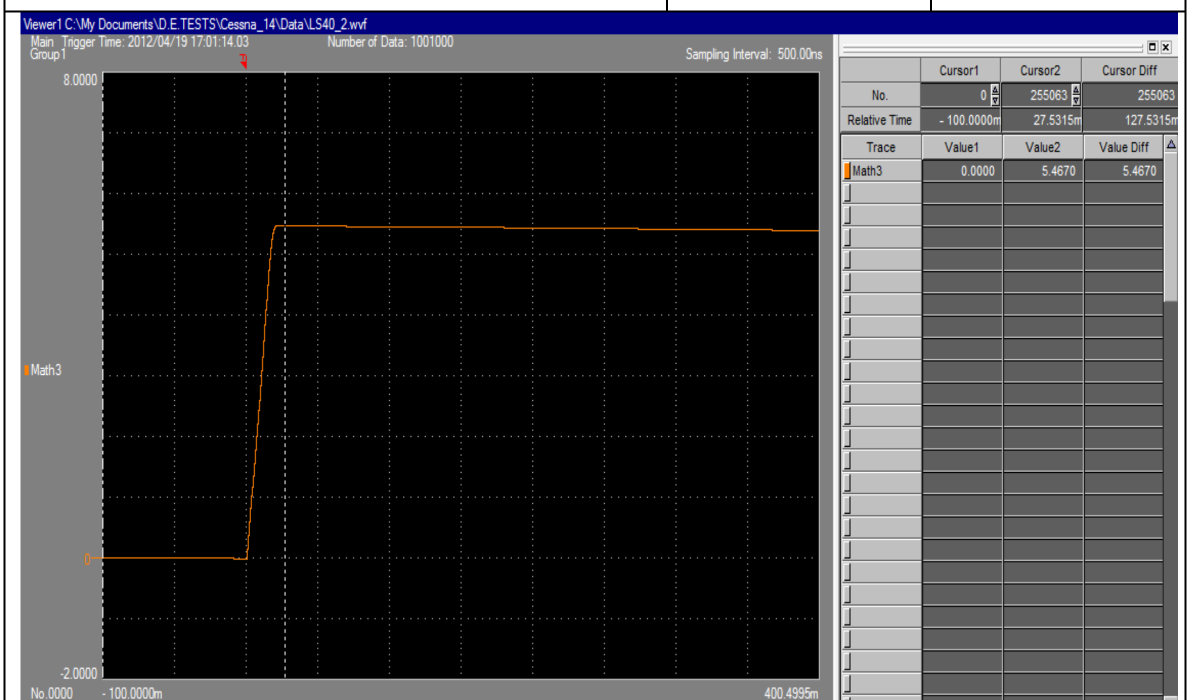


COMPONENT B CHARGE TRANSFER	11.335 Coulombs

PANEL: LS-40



HIGH CURRENT – COMPONENT C*	Ip = 342 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	5.5 Coulombs

PANEL: LS-40

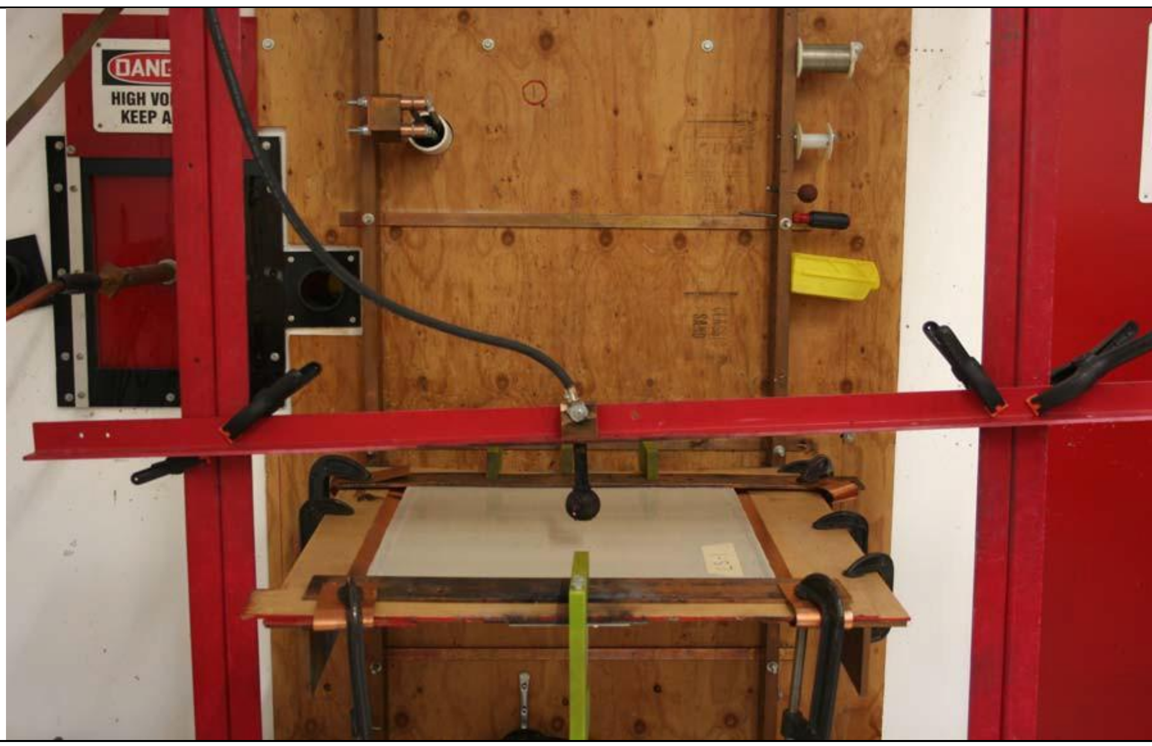
APPENDIX E

Photographs

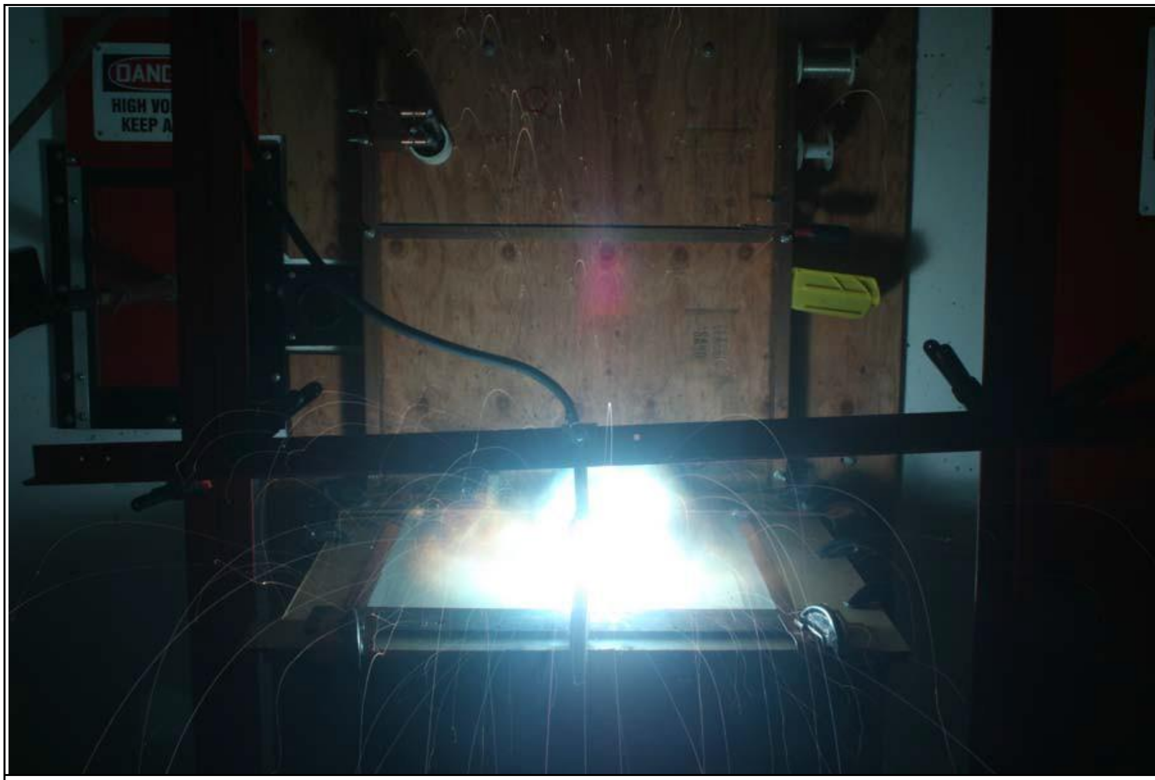
SIZE	CAGE CODE	DRAWING NO.
A	63242	TR056893
SCALE: NONE	REV LTR -	SHEET E1

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

High Current Test – Panel LS-1 Setup



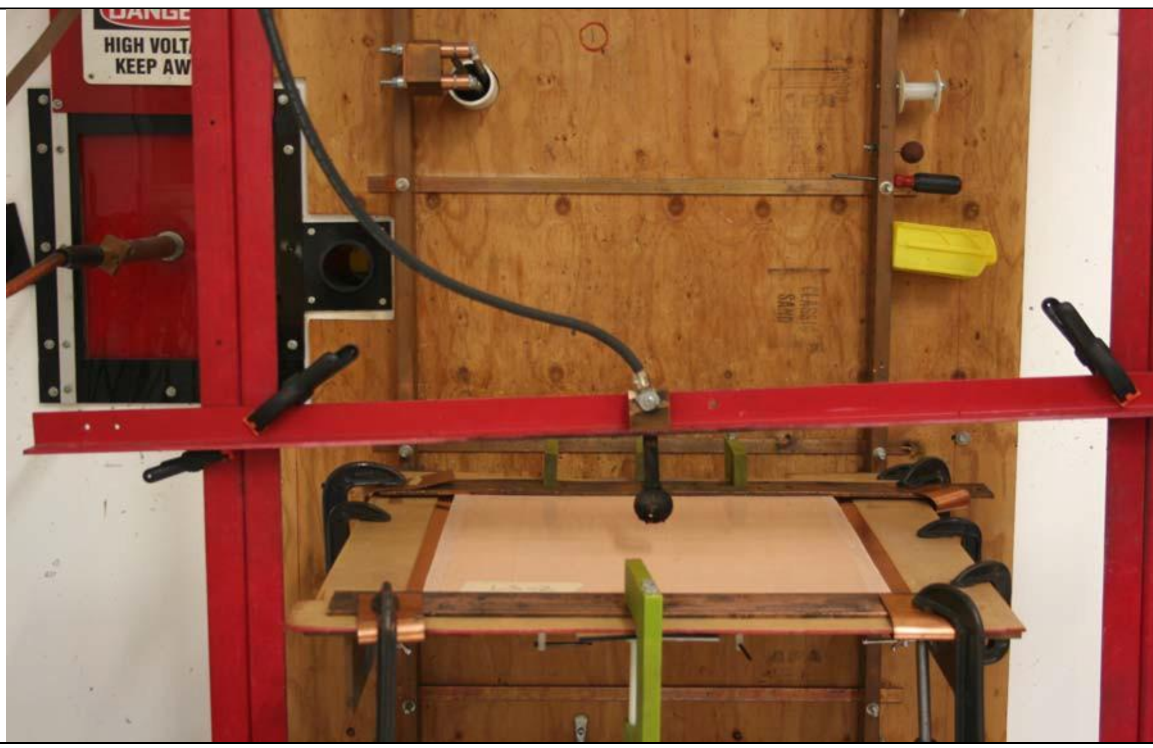
High Current Test – Panel LS-1 Pre-Strike



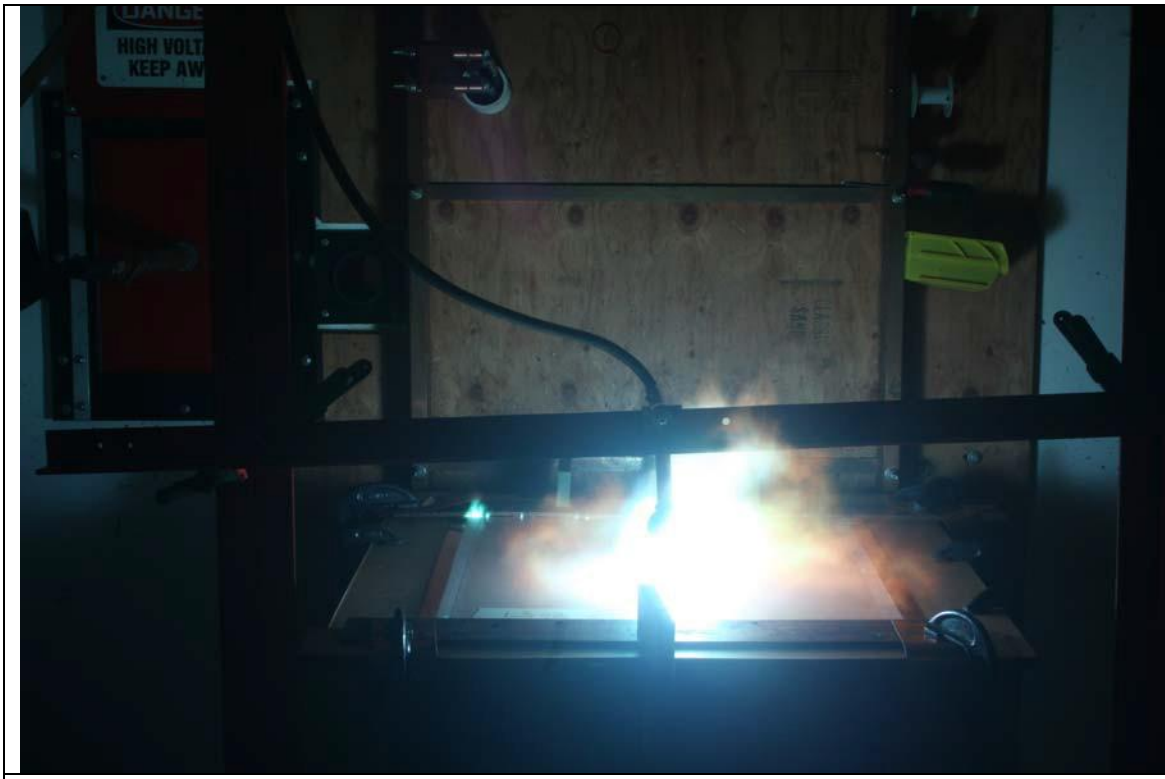
High Current Test – Panel LS-1 Components D, B, C*

High Current Test – Panel LS-1 Post-Strike Damage

High Current Test – Panel LS-2 Setup



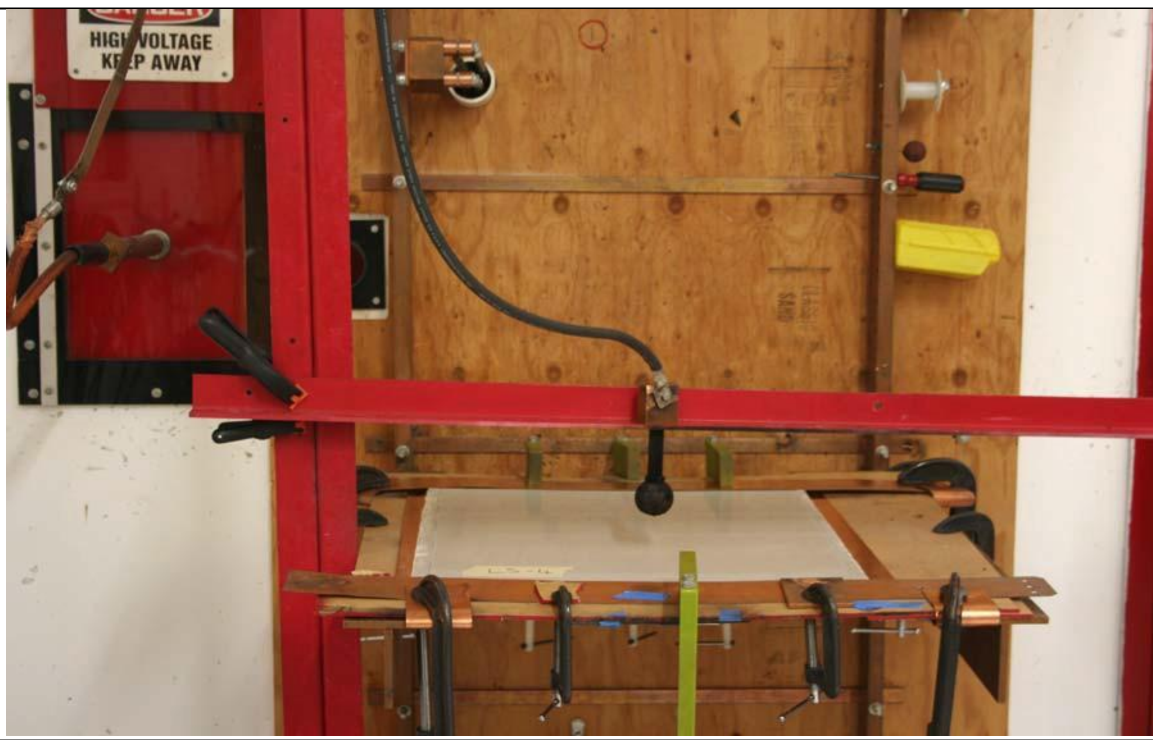
High Current Test – Panel LS-2 Pre-Strike



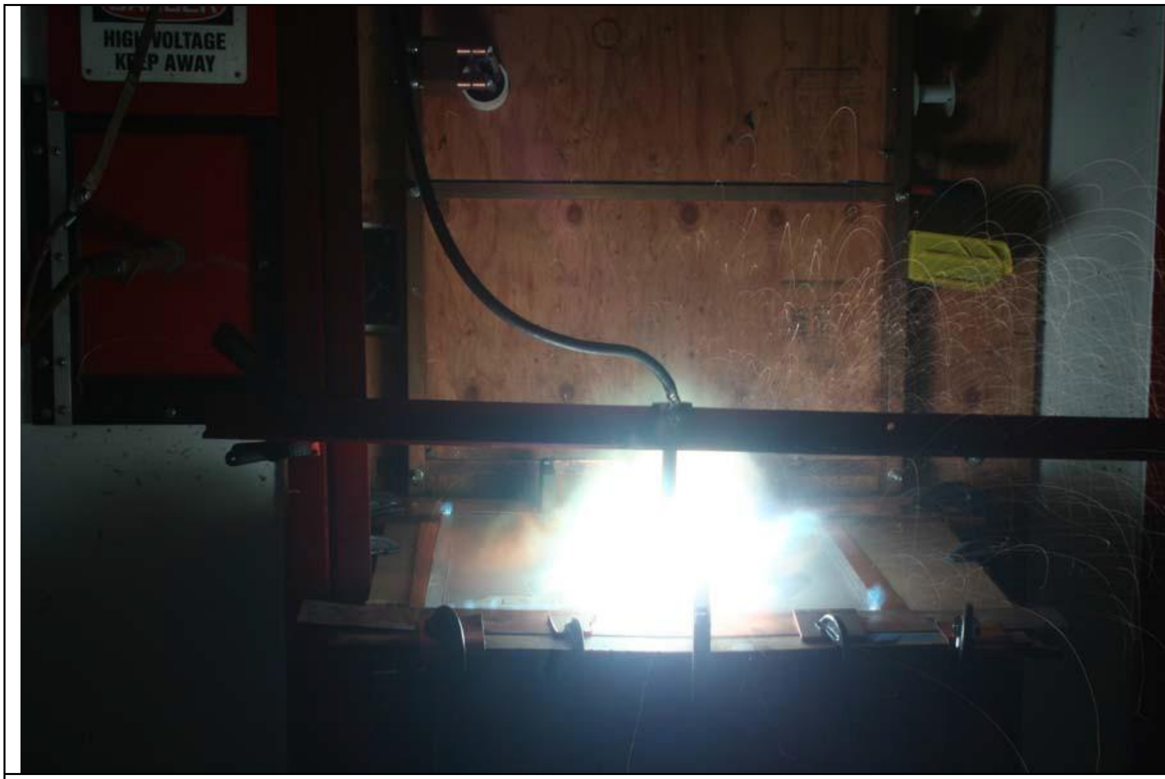
High Current Test – Panel LS-2 Components D, B, C*

High Current Test – Panel LS-2 Post-Strike Damage

High Current Test – Panel LS-4 Setup



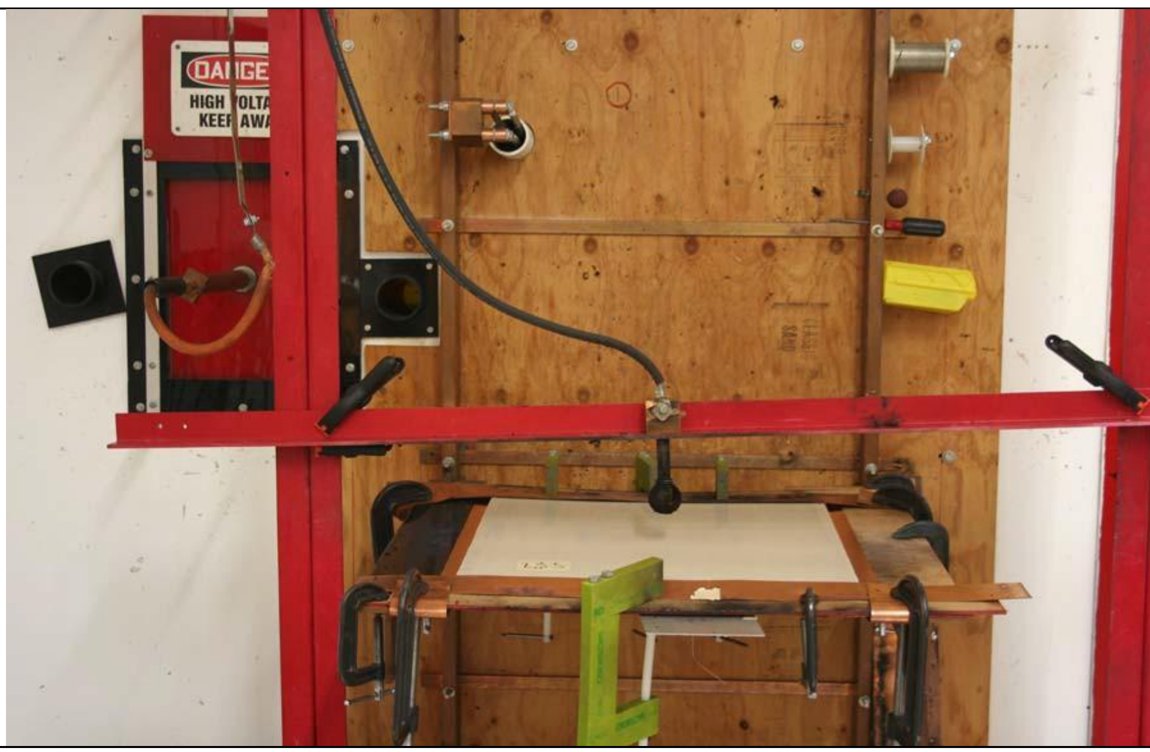
High Current Test – Panel LS-4 Pre-Strike



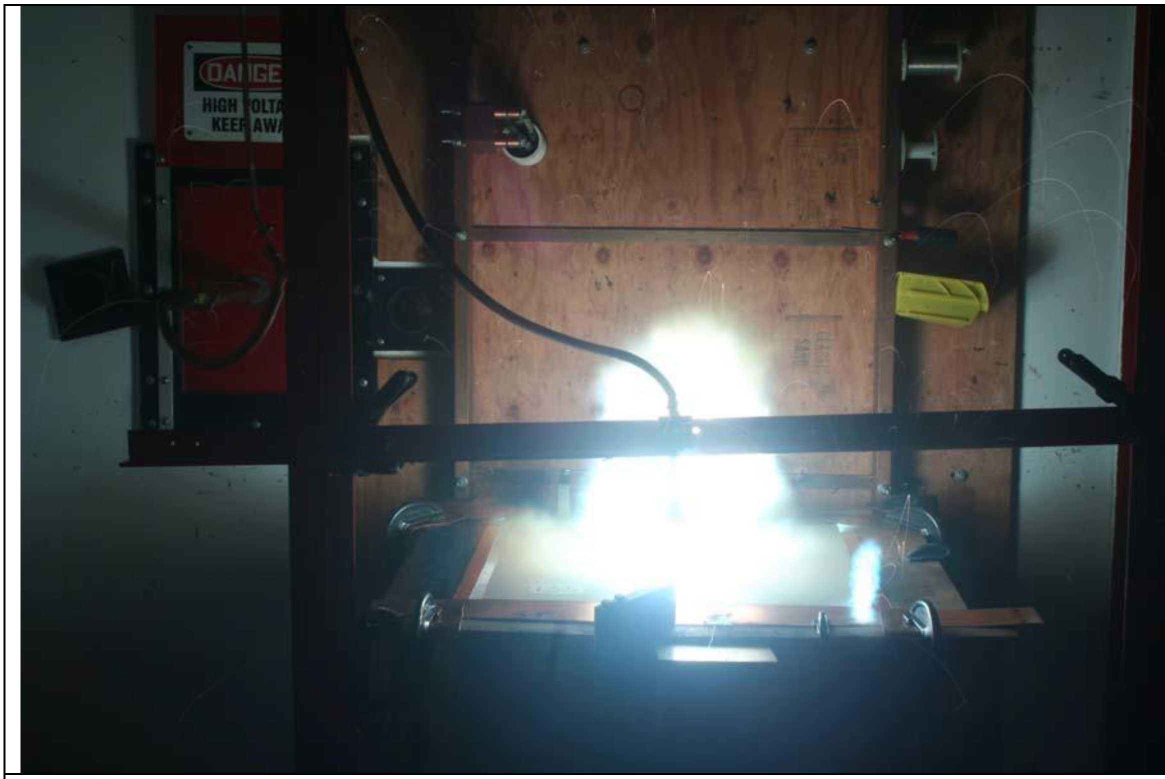
High Current Test – Panel LS-4 Components D, B, C*

High Current Test – Panel LS-4 Post-Strike Damage

High Current Test – Panel LS-5 Setup

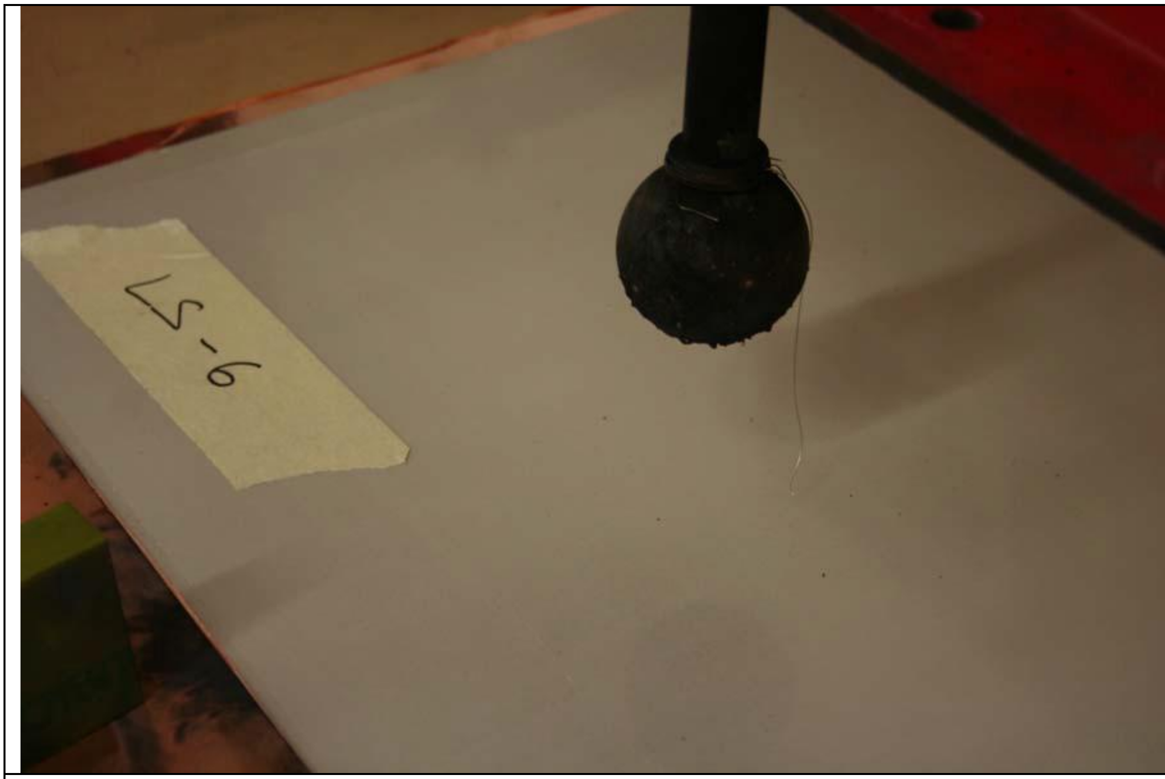


High Current Test – Panel LS-5 Pre-Strike

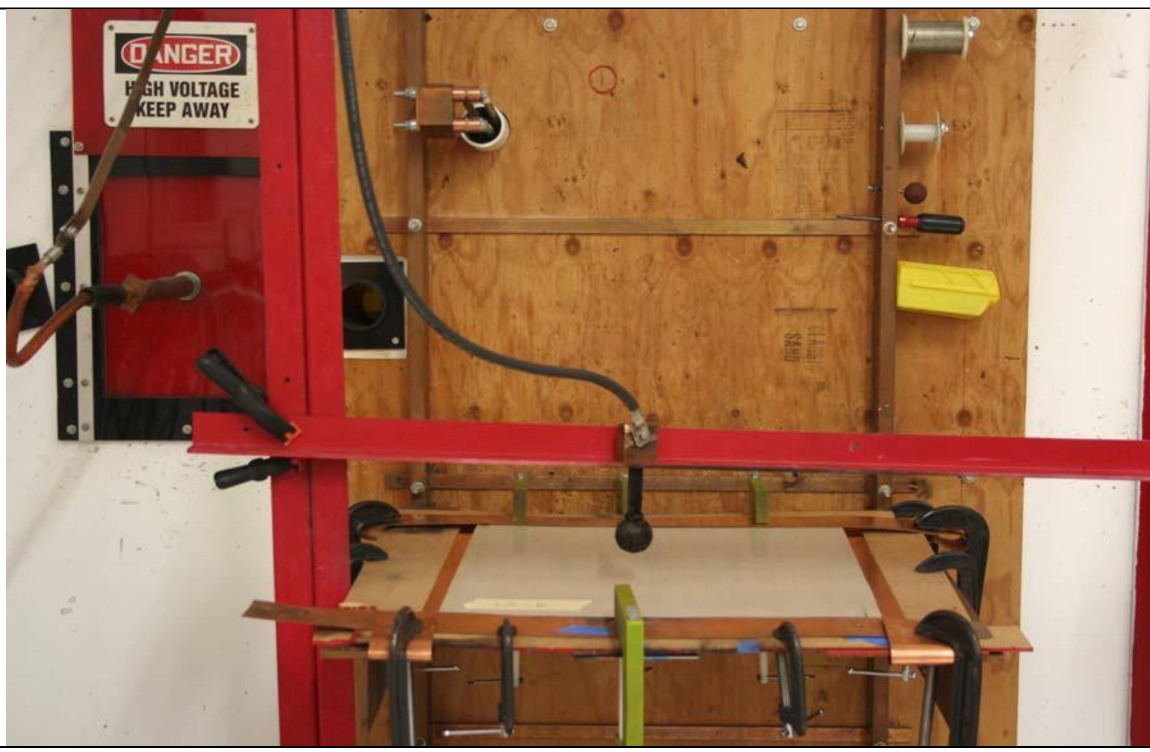


High Current Test – Panel LS-5 Components D, B, C*

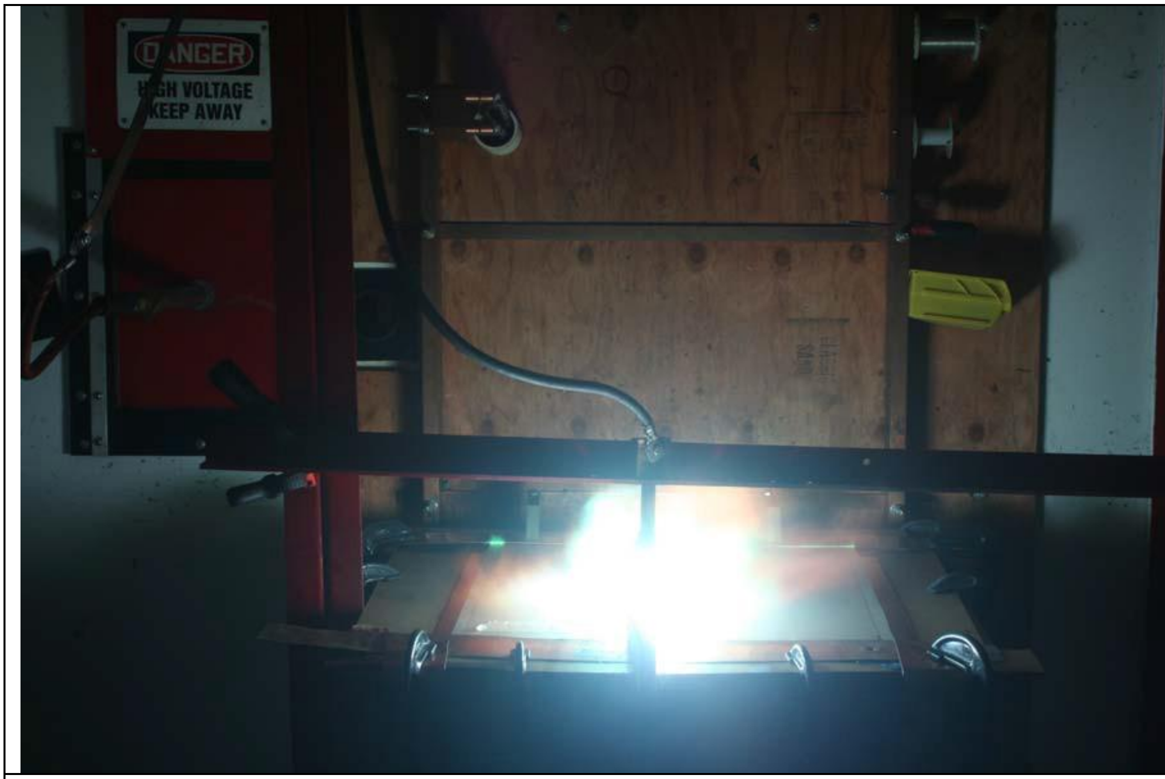
High Current Test – Panel LS-5 Post-Strike Damage



High Current Test – Panel LS-6 Setup



High Current Test – Panel LS-6 Pre-Strike

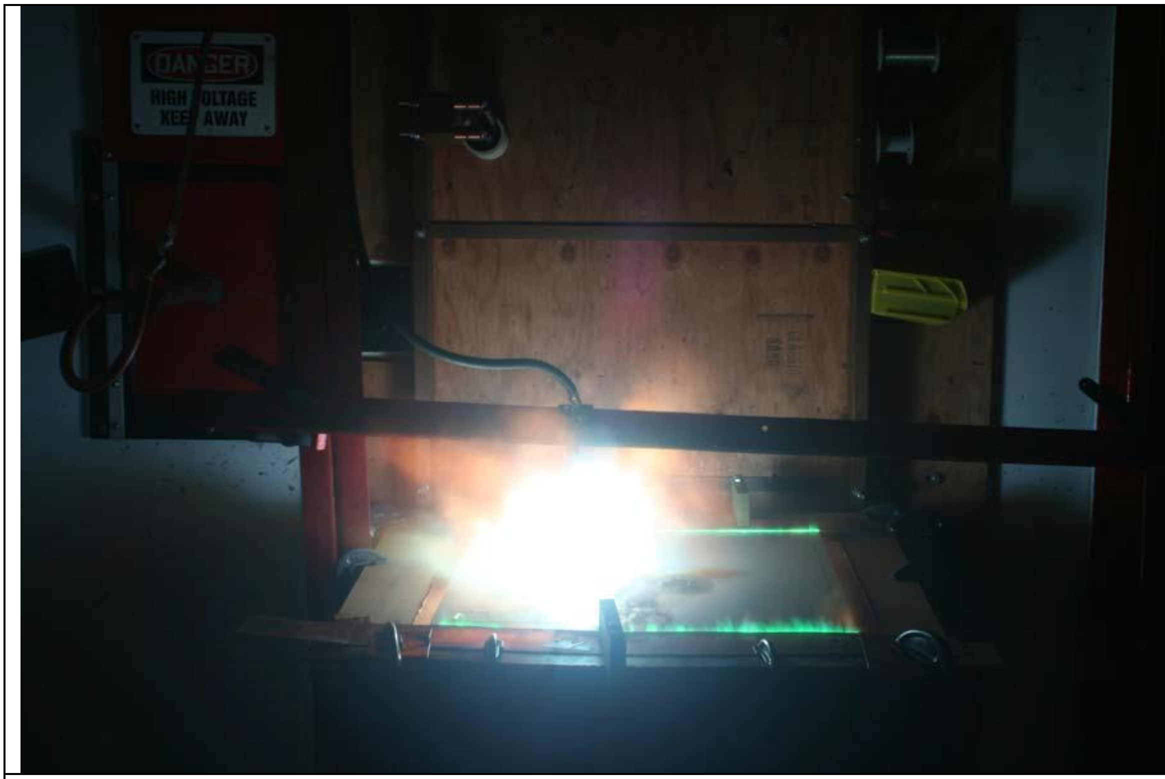


High Current Test – Panel LS-6 Components D, B, C*

High Current Test – Panel LS-6 Post-Strike Damage

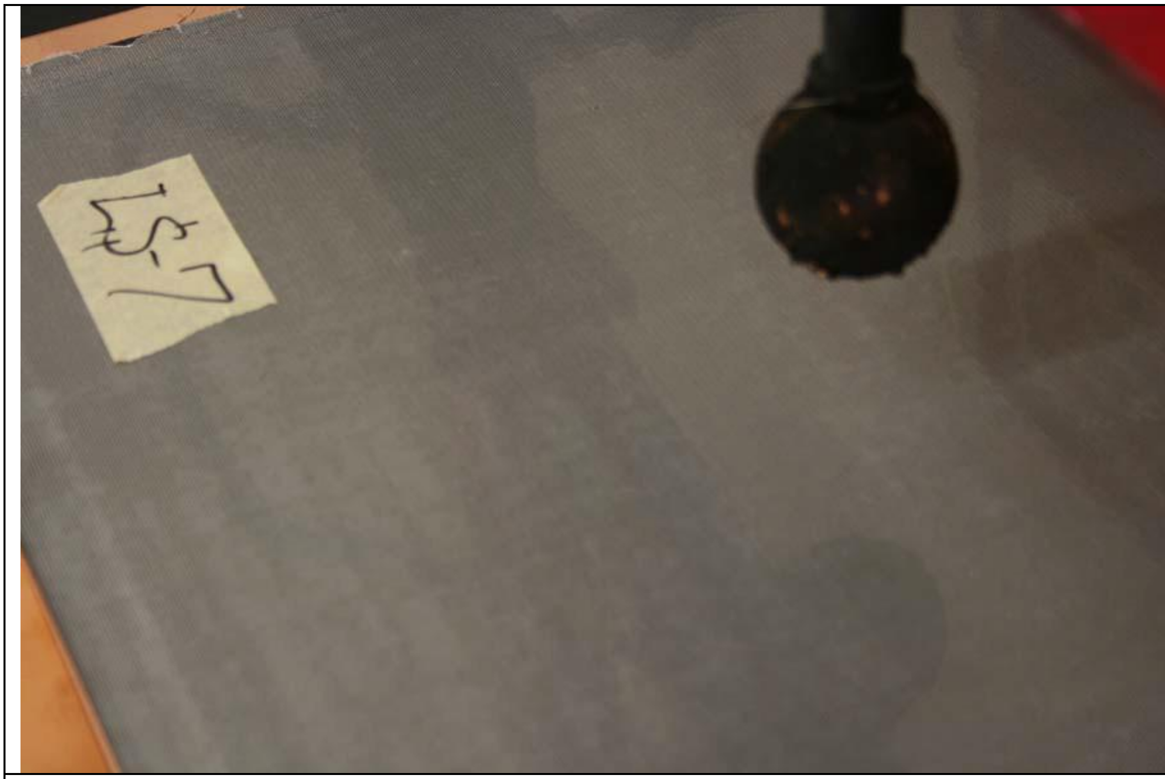
High Current Test – Panel LS-6 Setup

High Current Test – Panel LS-6 Pre-Strike

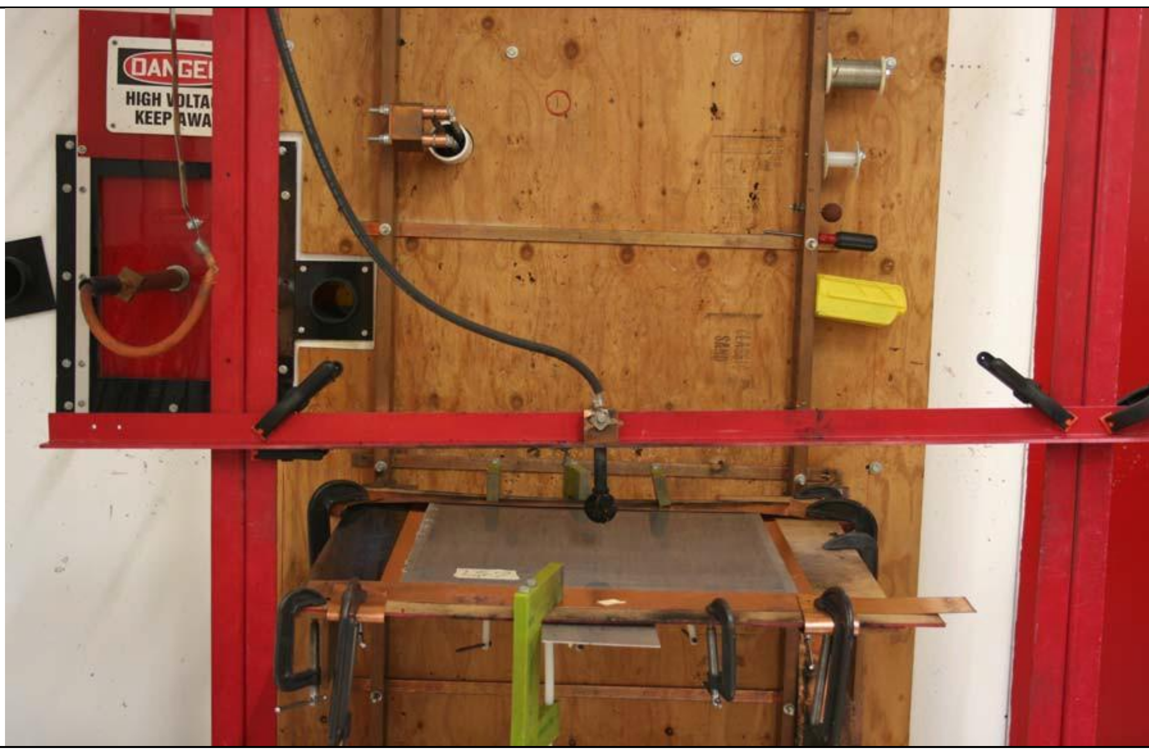


High Current Test – Panel LS-6 Components D, B, C*

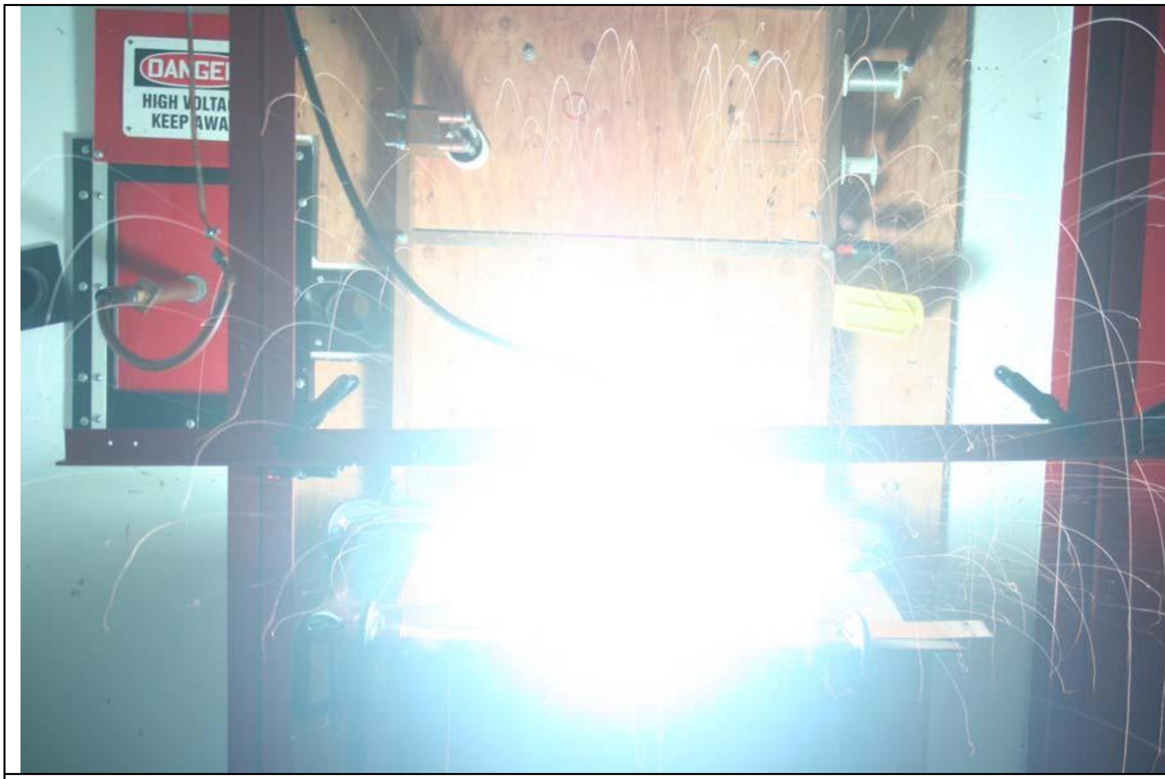
High Current Test – Panel LS-6 Post-Strike Damage



High Current Test – Panel LS-7 Setup

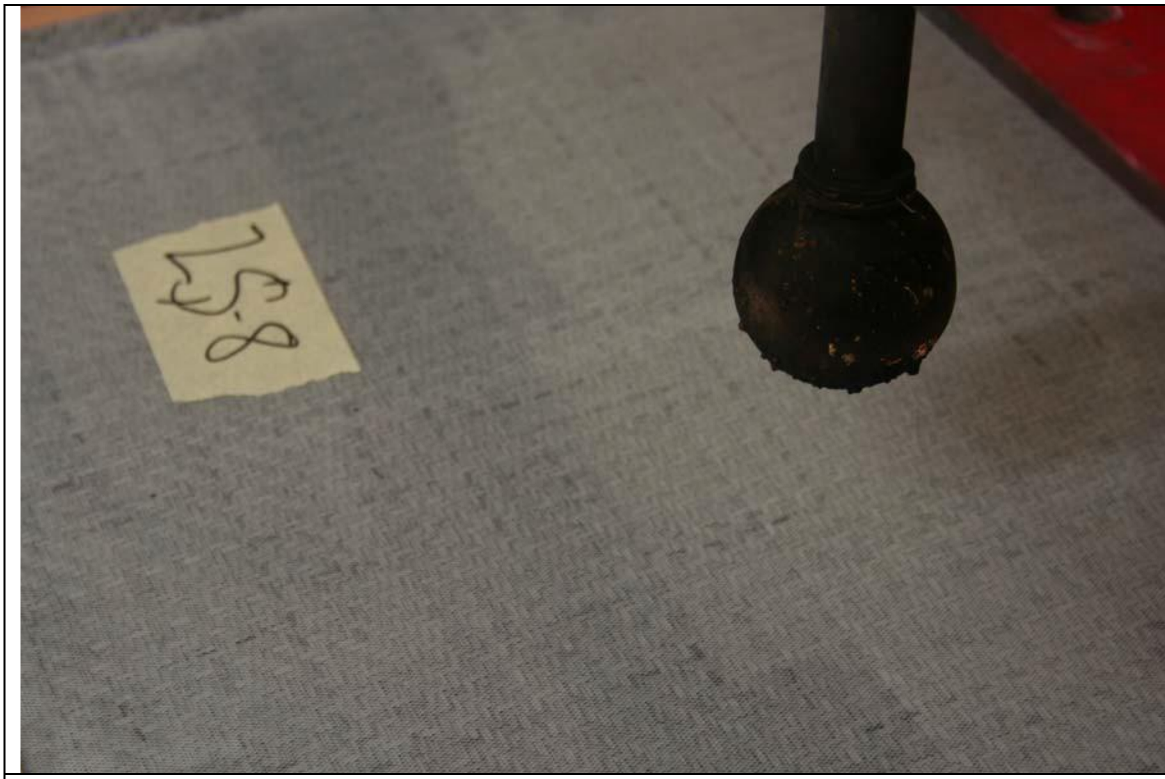


High Current Test – Panel LS-7 Pre-Strike



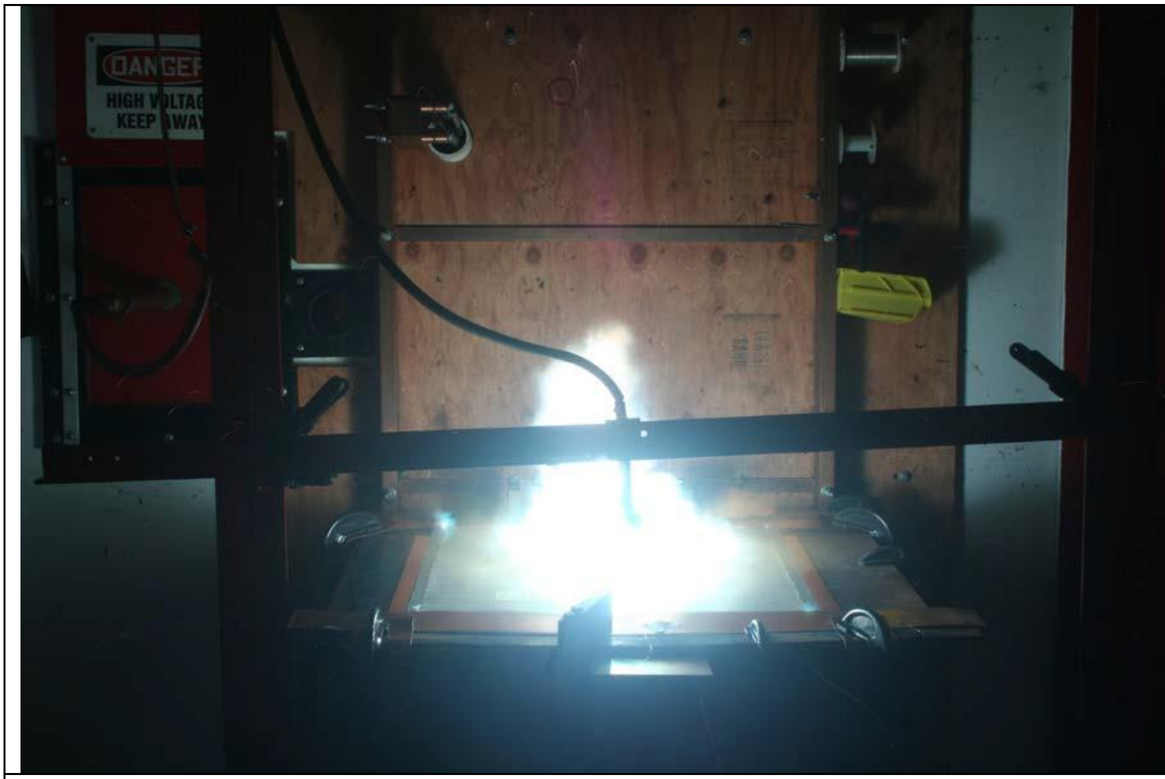
High Current Test – Panel LS-7 Components D, B, C*

High Current Test – Panel LS-7 Post-Strike Damage



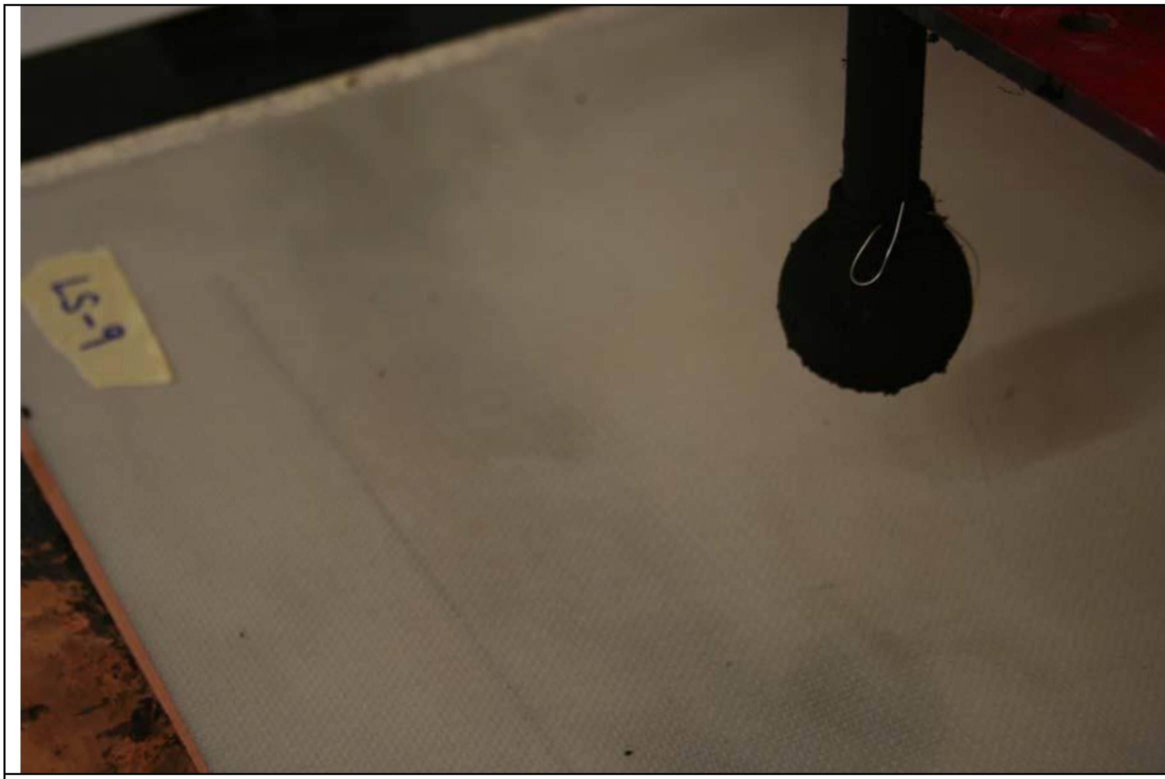
High Current Test – Panel LS-8 Setup

High Current Test – Panel LS-8 Pre-Strike



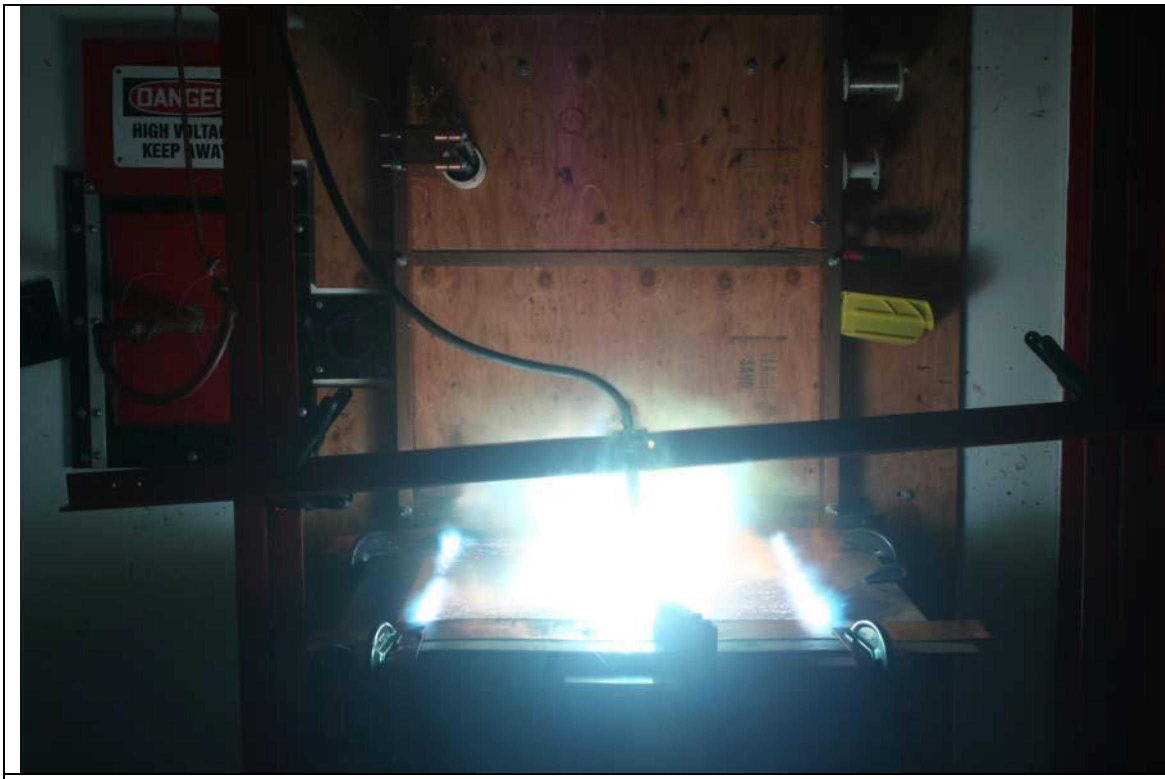
High Current Test – Panel LS-8 Components D, B, C*

High Current Test – Panel LS-8 Post-Strike Damage



High Current Test – Panel LS-9 Setup

High Current Test – Panel LS-9 Pre-Strike

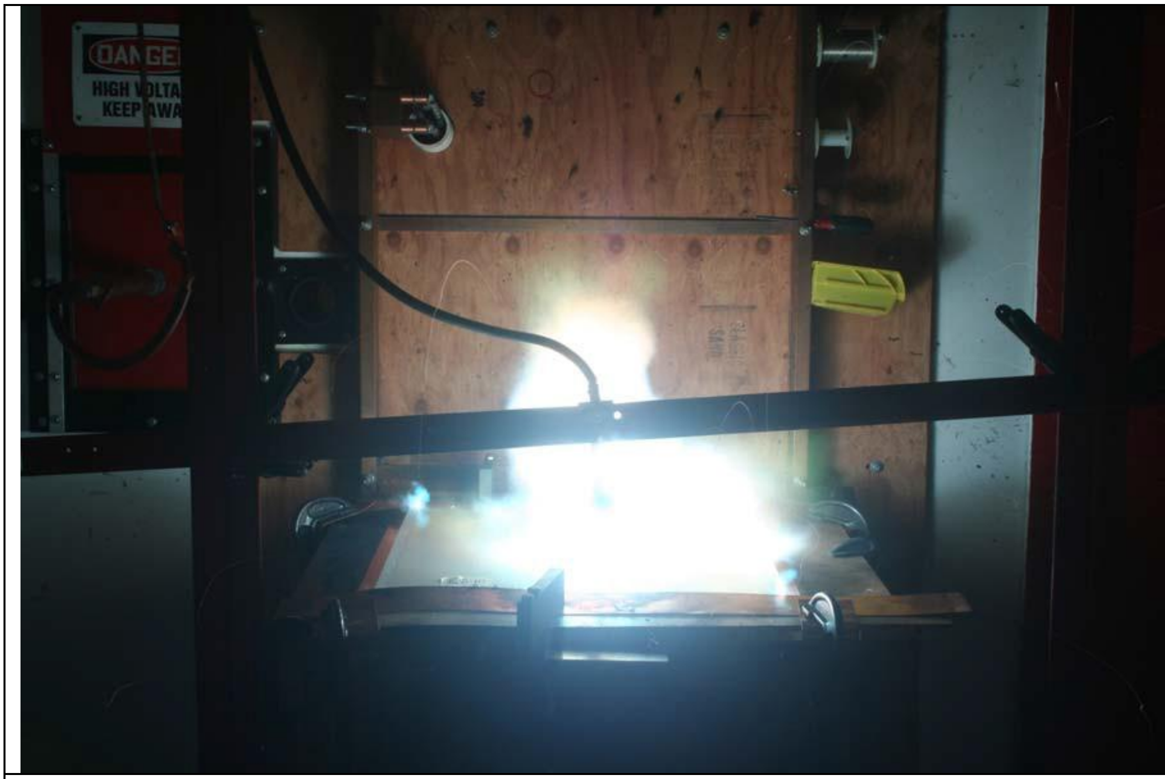


High Current Test – Panel LS-9 Components D, B, C*

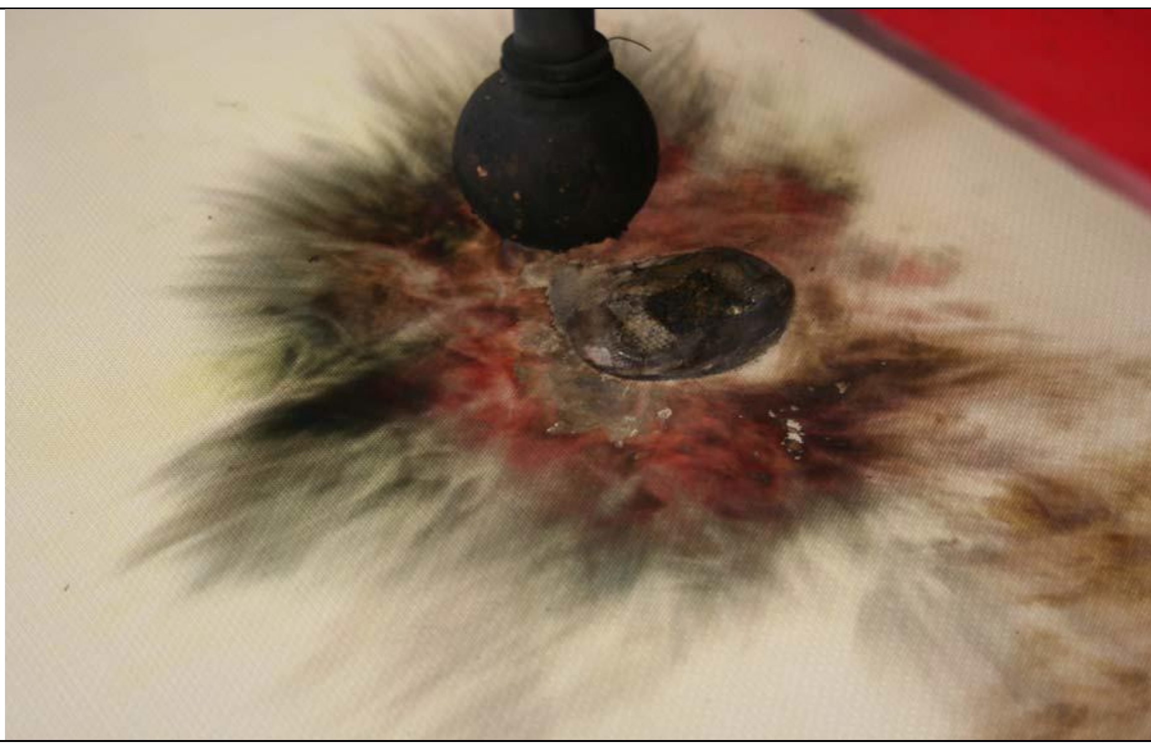
High Current Test – Panel LS-9 Post-Strike Damage

High Current Test – Panel LS-10 Setup

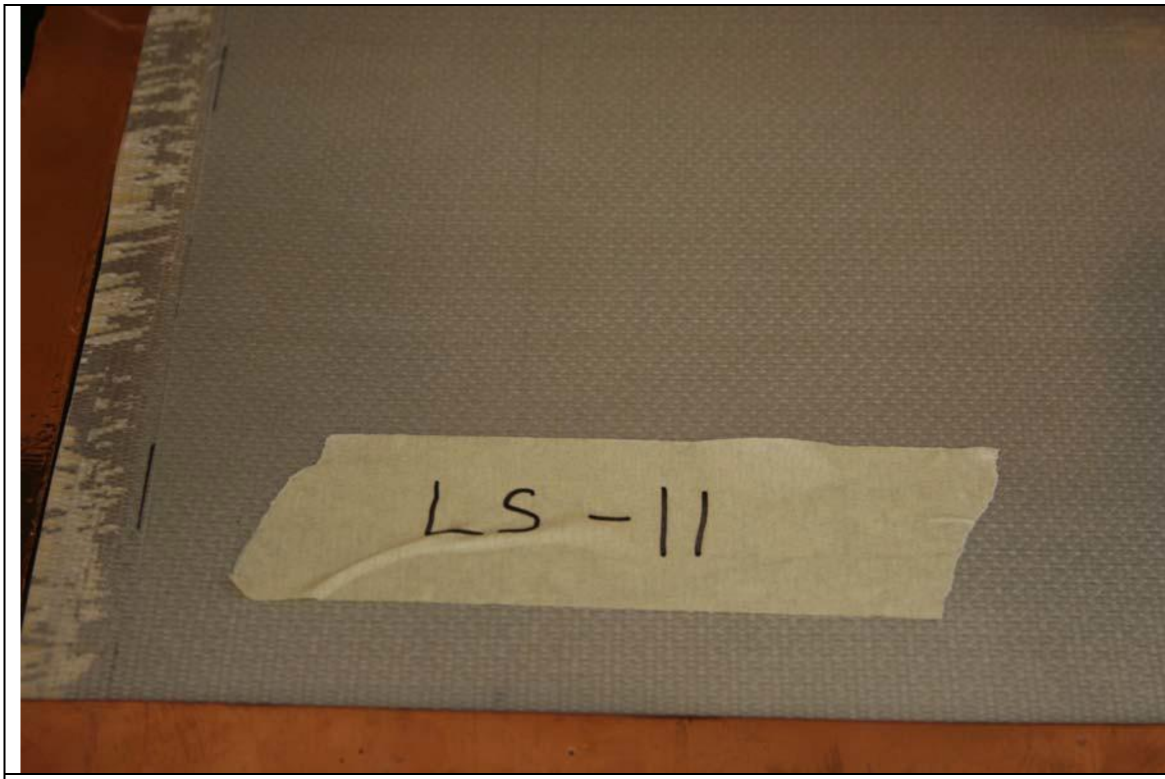
High Current Test – Panel LS-10 Pre-Strike



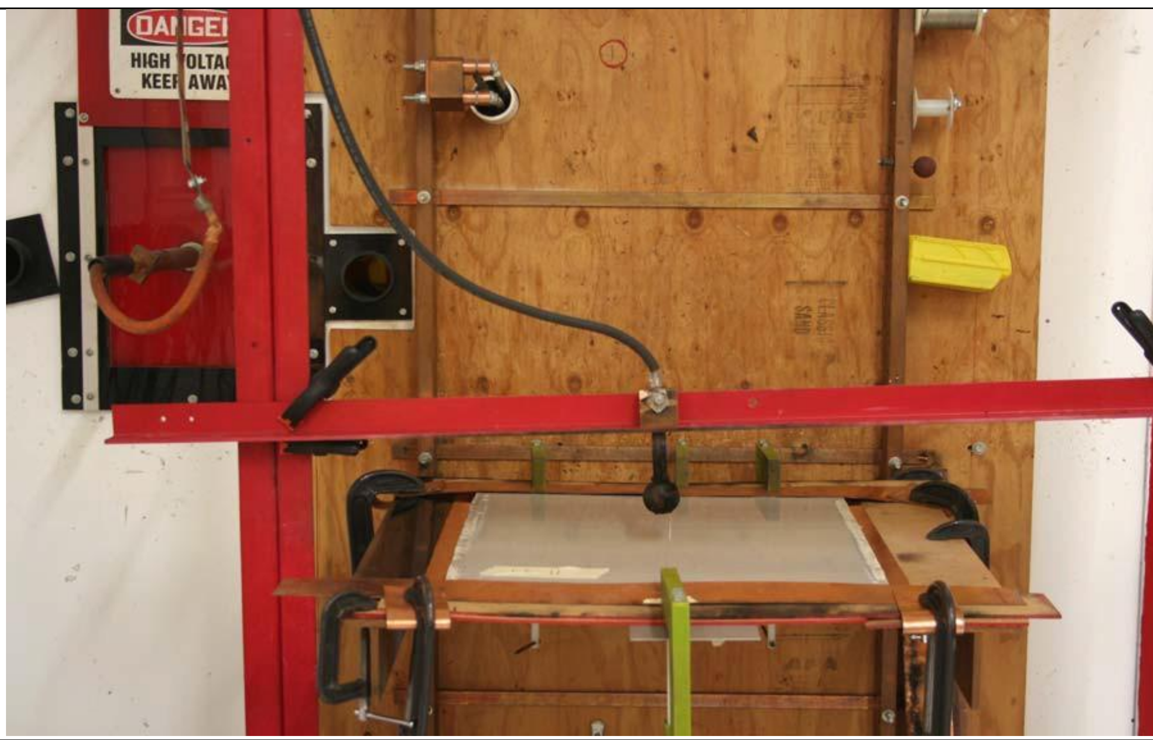
High Current Test – Panel LS-10 Components D, B, C*



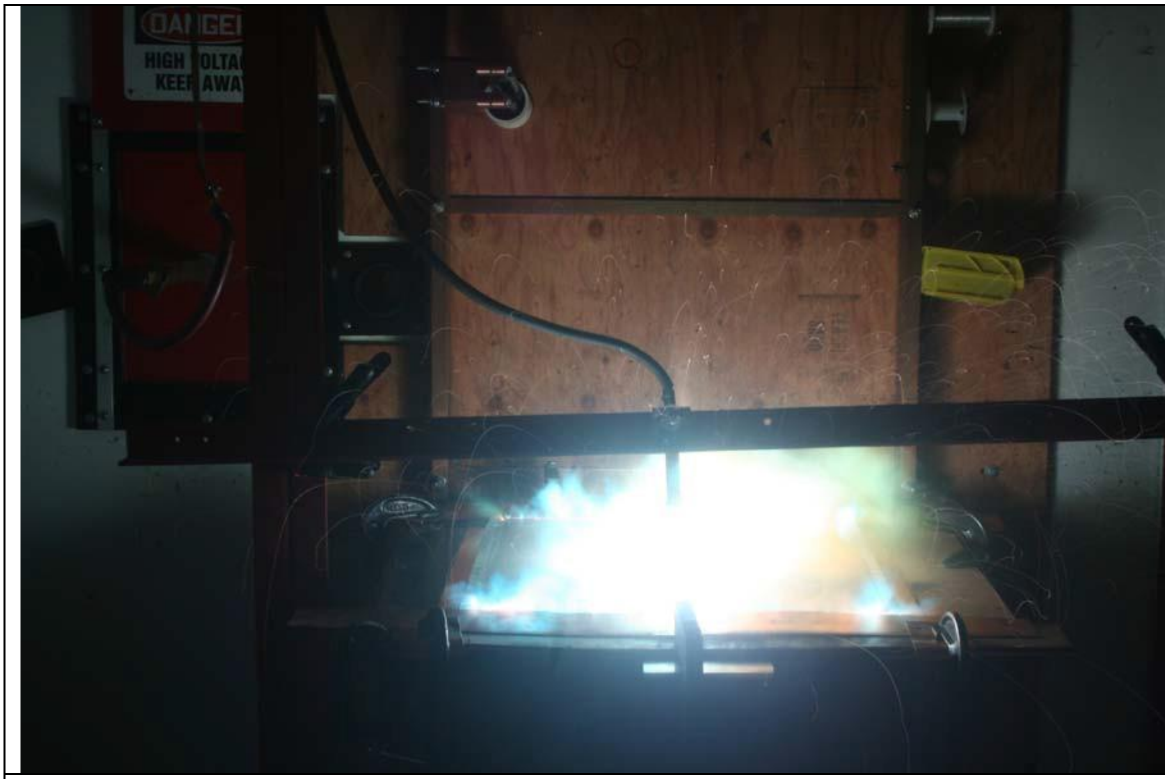
High Current Test – Panel LS-10 Post-Strike Damage



High Current Test – Panel LS-11 Setup



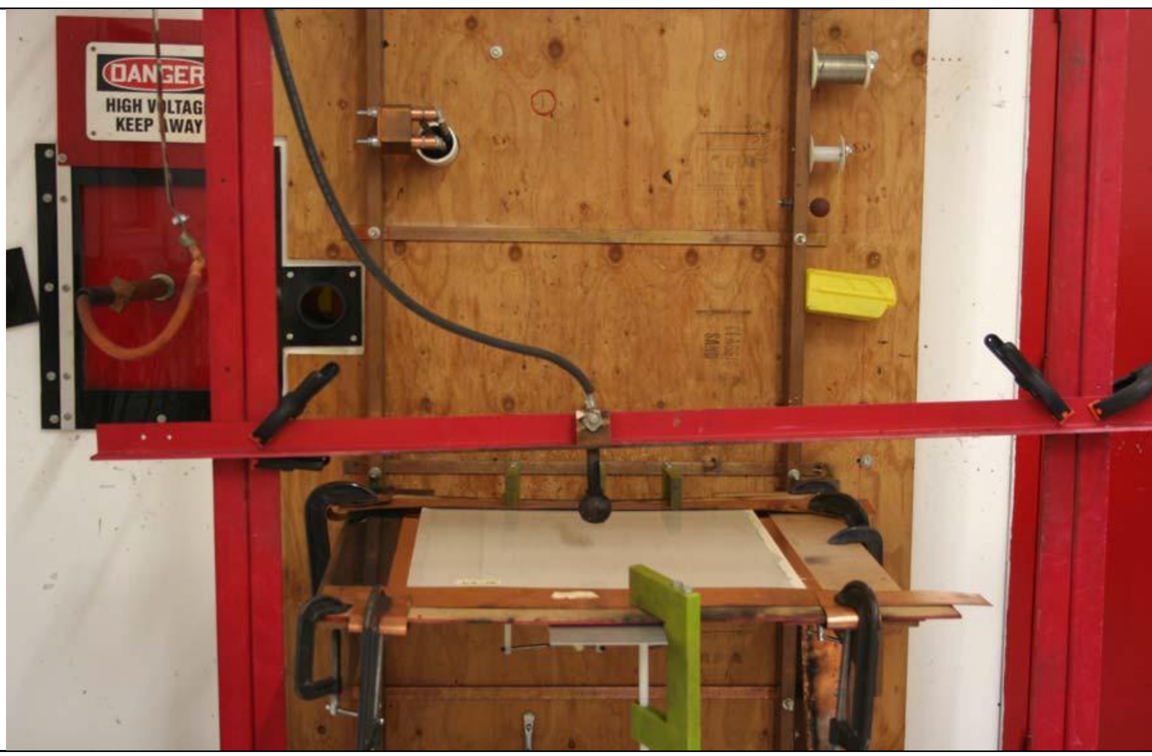
High Current Test – Panel LS-11 Pre-Strike



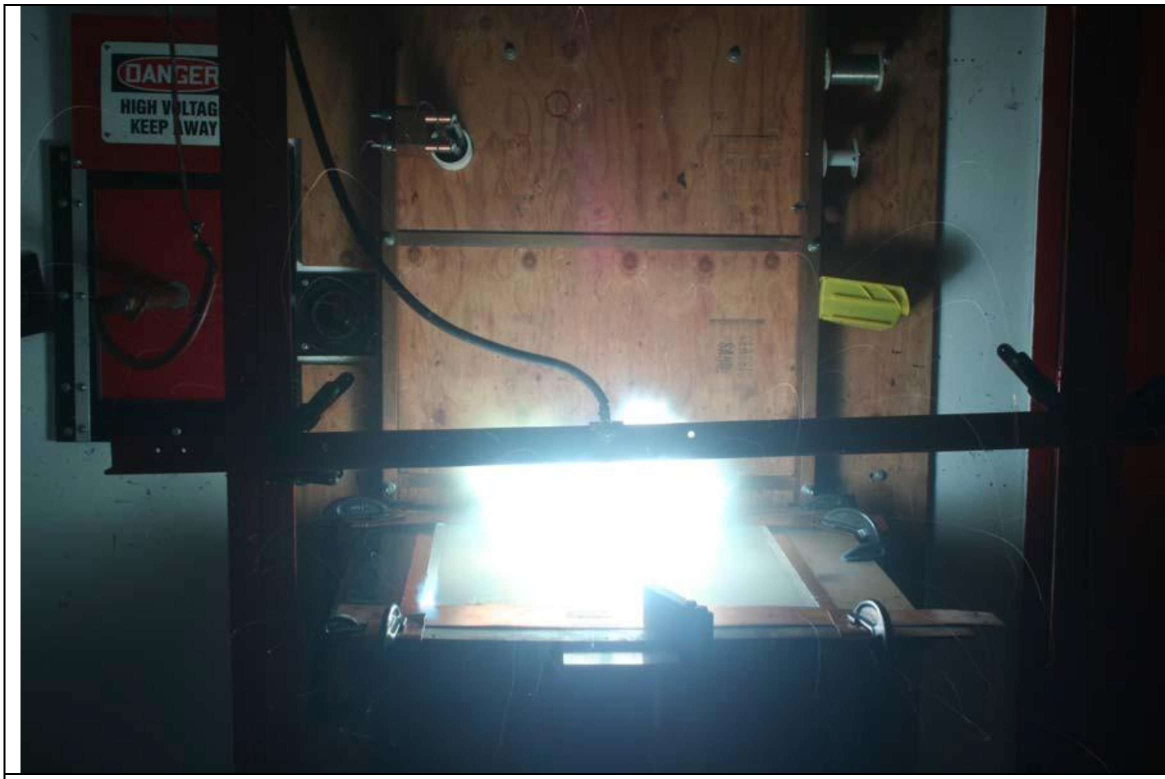
High Current Test – Panel LS-11 Components D, B, C*

High Current Test – Panel LS-11 Post-Strike Damage

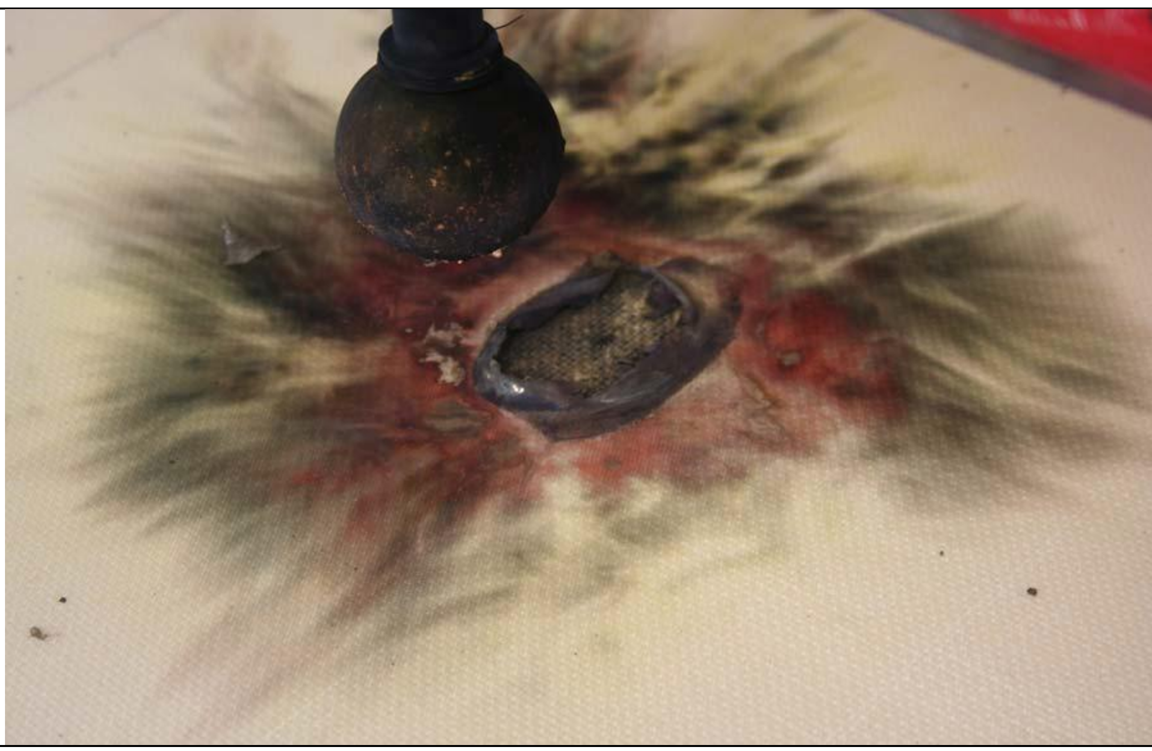
High Current Test – Panel LS-12 Setup



High Current Test – Panel LS-12 Pre-Strike

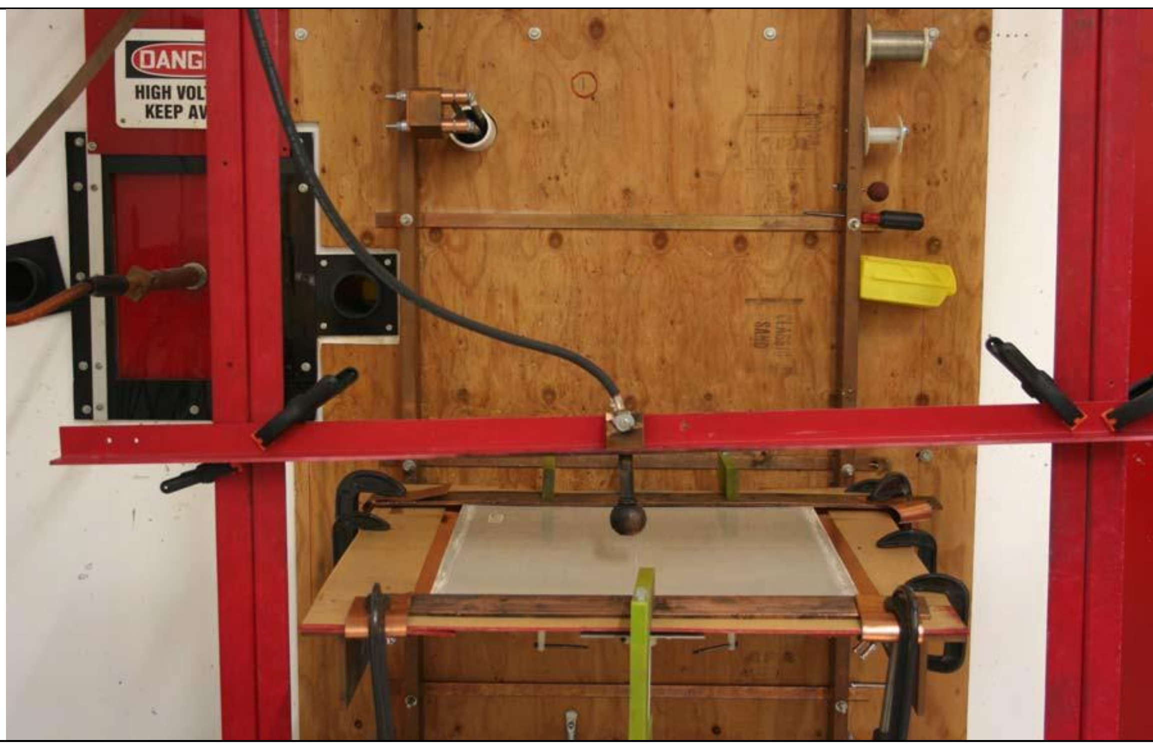


High Current Test – Panel LS-12 Components D, B, C*

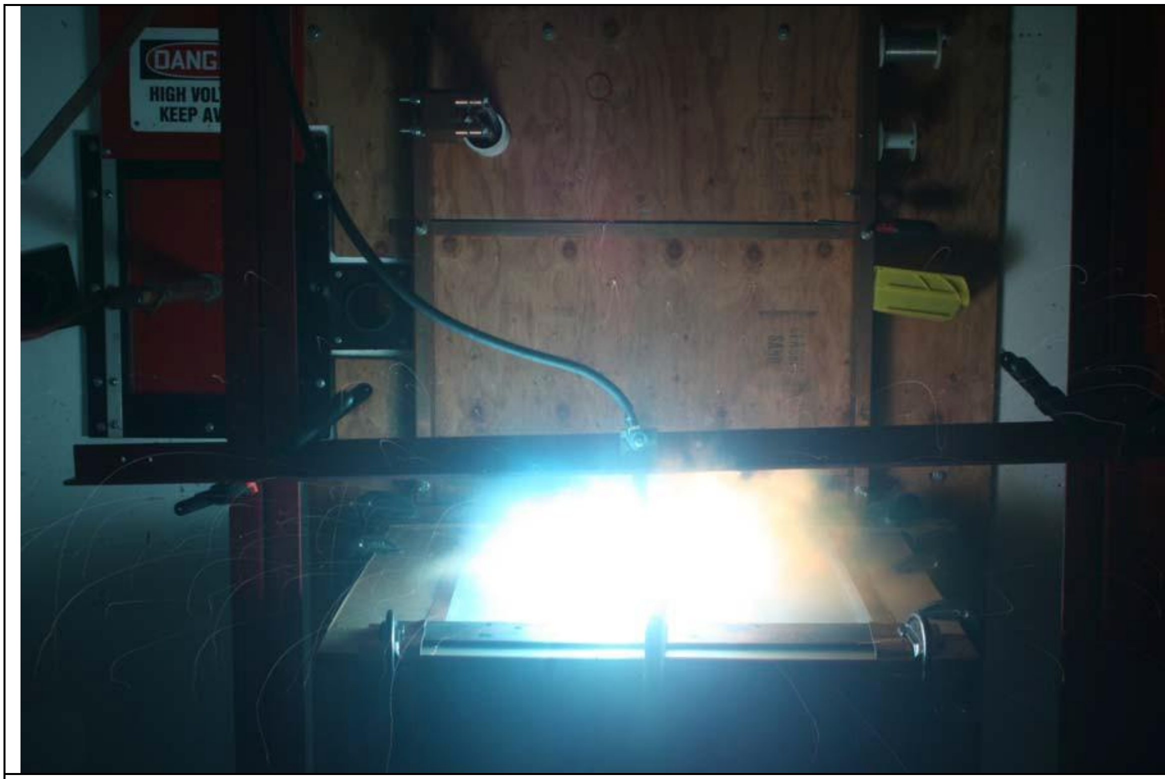


High Current Test – Panel LS-12 Post-Strike Damage

High Current Test – Panel LS-13 Setup



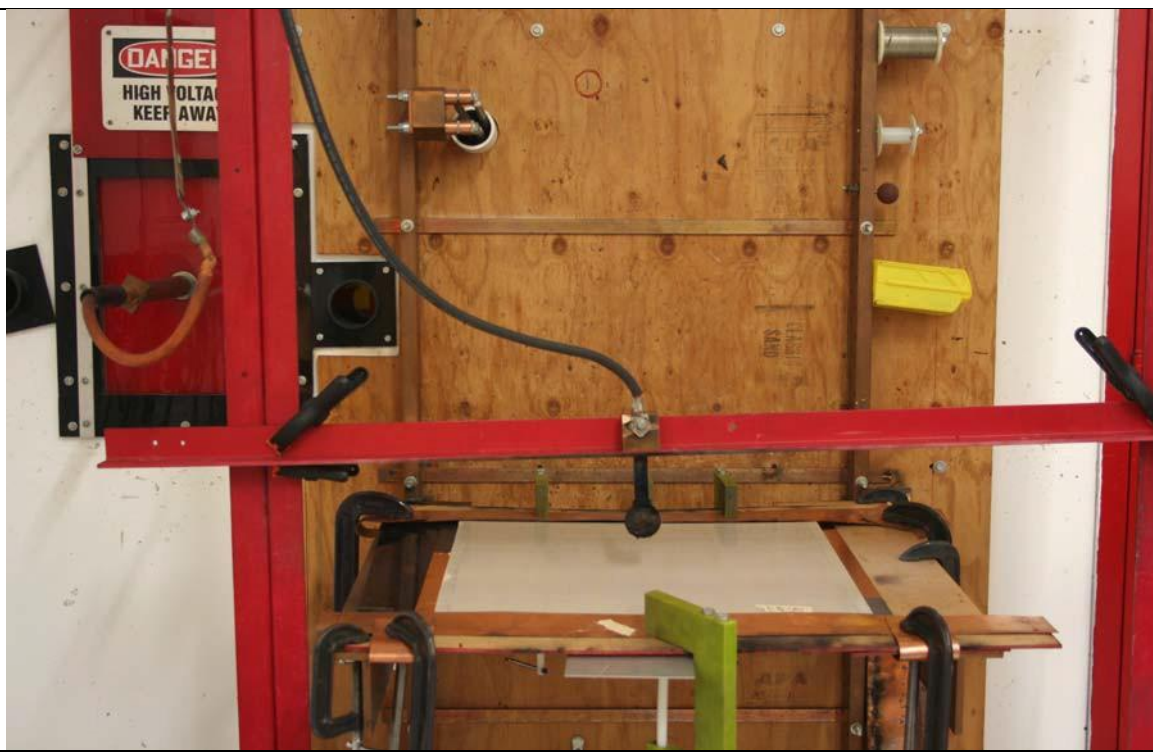
High Current Test – Panel LS-13 Pre-Strike



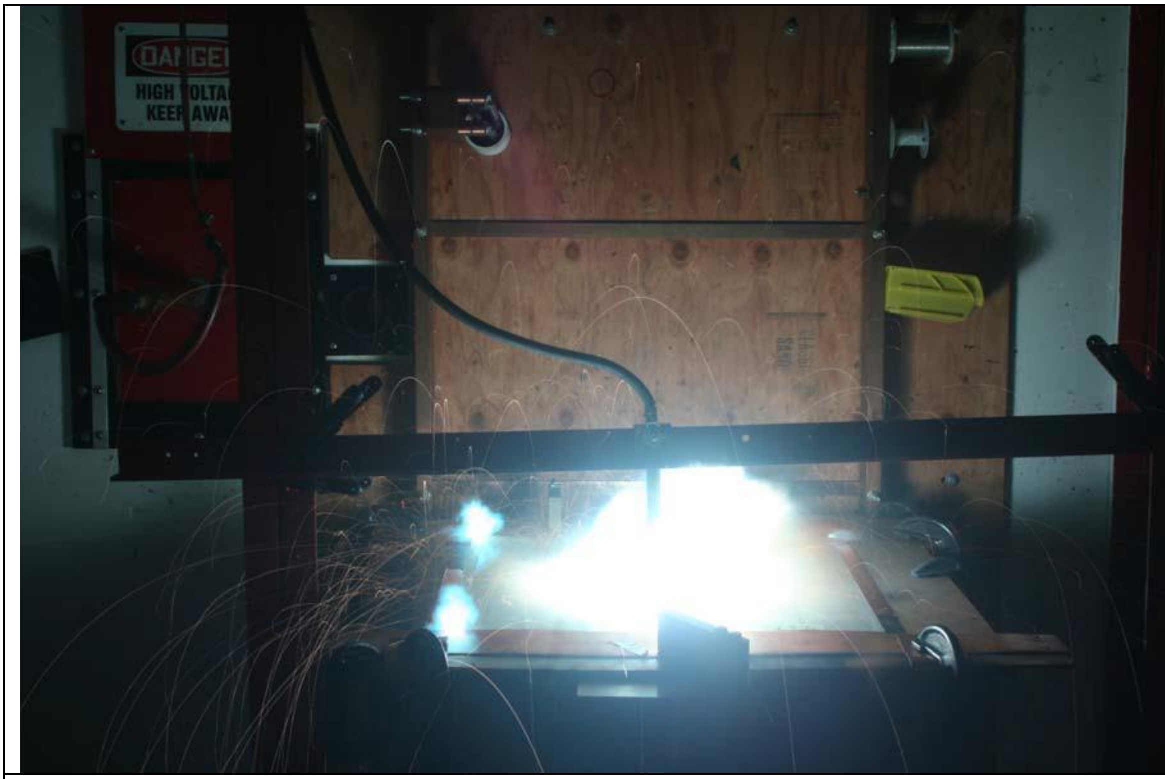
High Current Test – Panel LS-13 Components D, B, C*

High Current Test – Panel LS-13 Post-Strike Damage

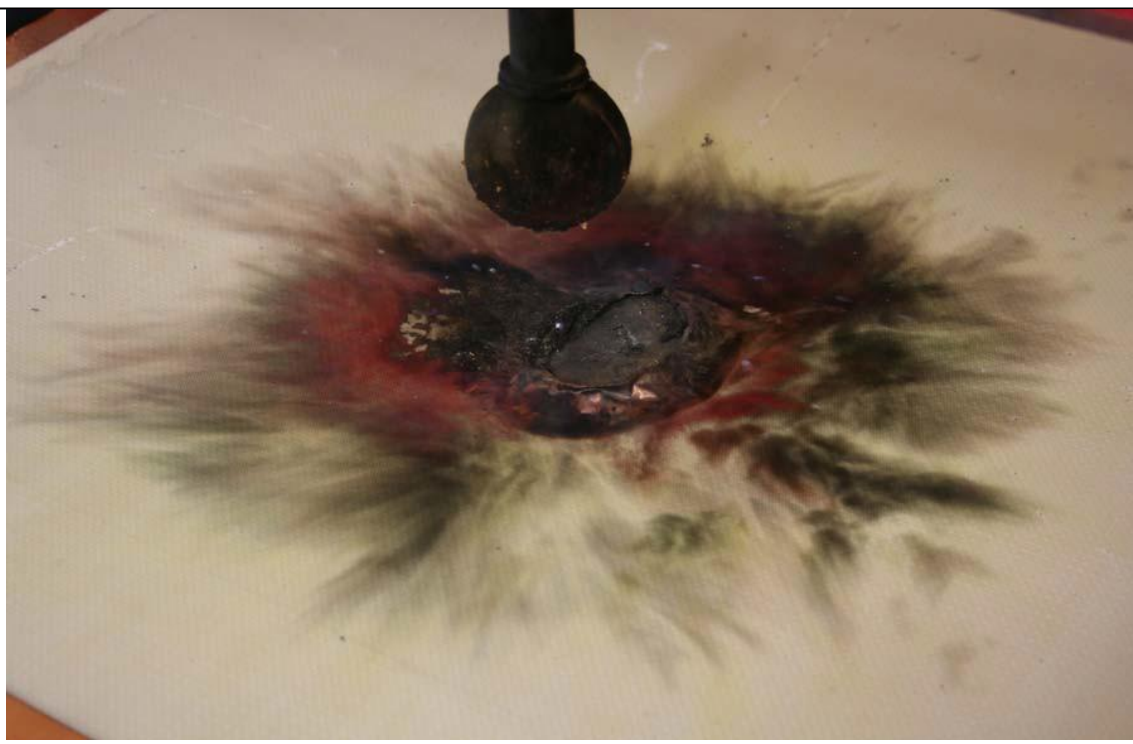
High Current Test – Panel LS-14 Setup



High Current Test – Panel LS-14 Pre-Strike

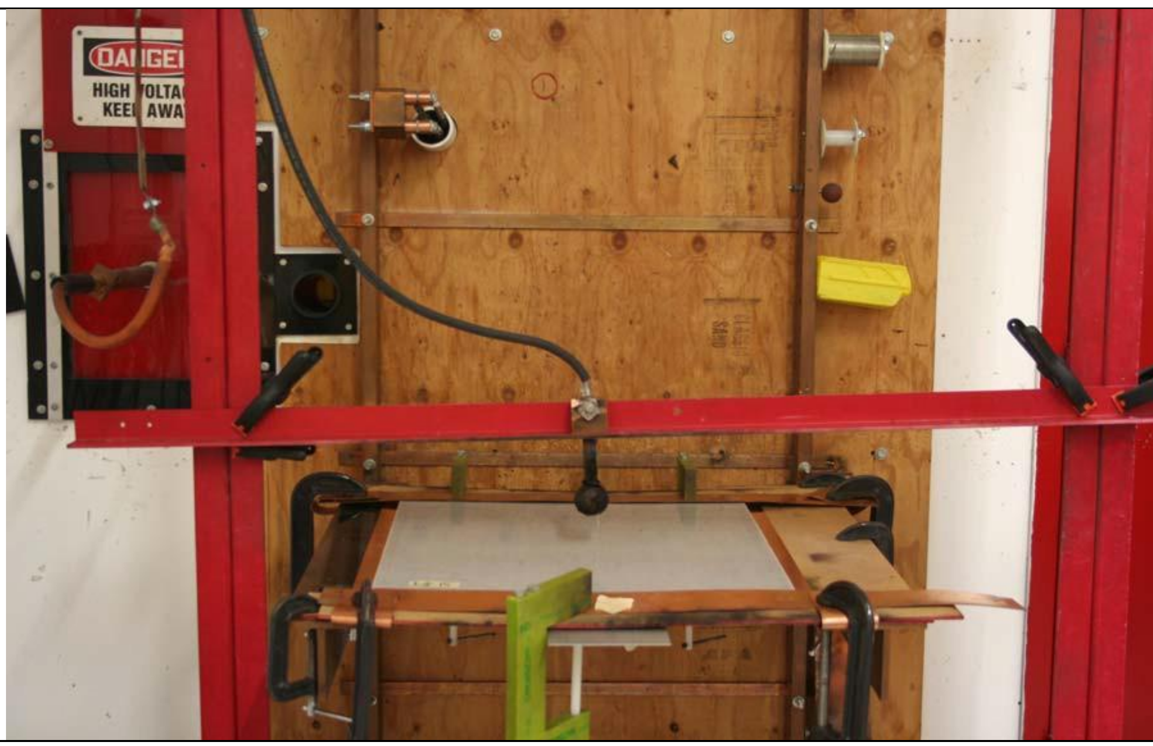


High Current Test – Panel LS-14 Components D, B, C*

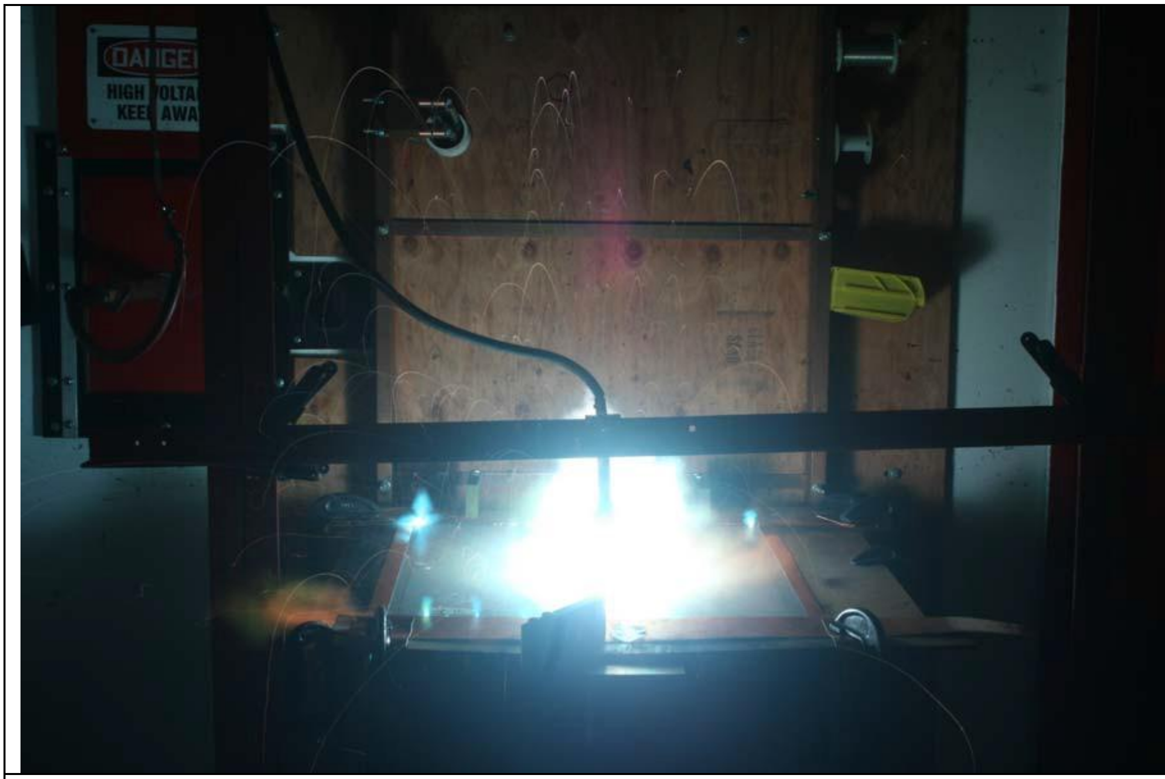


High Current Test – Panel LS-14 Post-Strike Damage

High Current Test – Panel LS-15 Setup

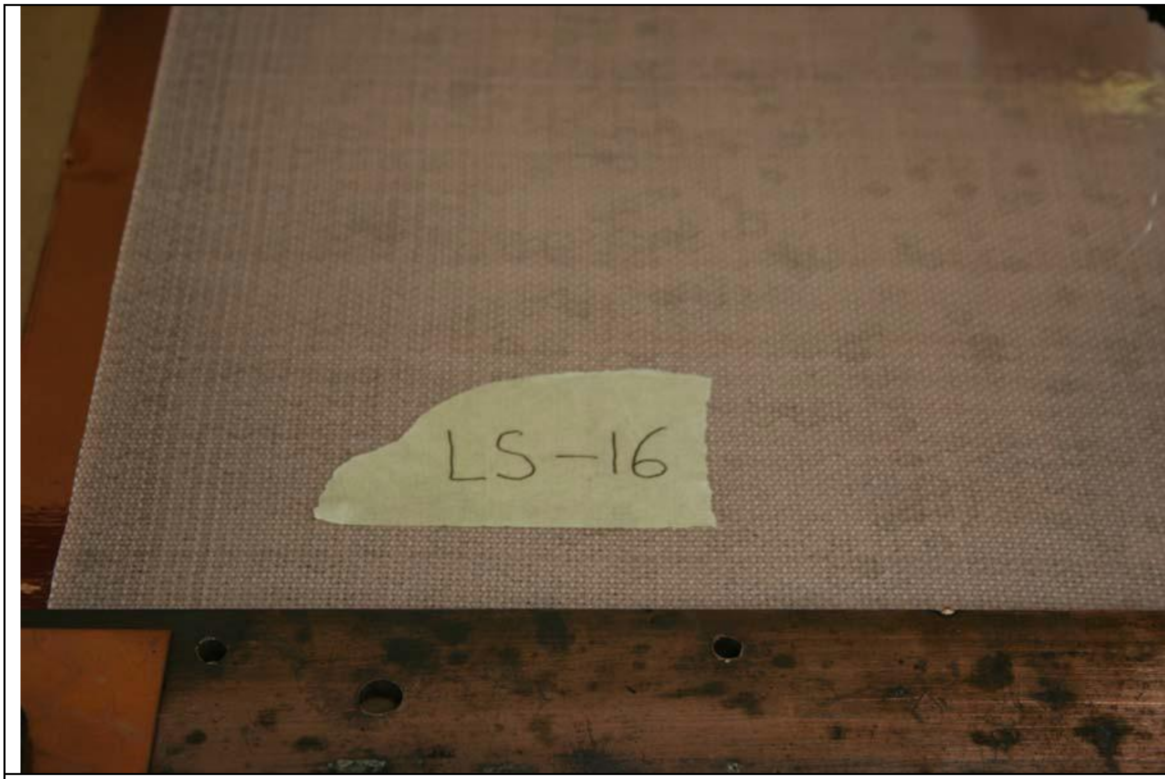


High Current Test – Panel LS-15 Pre-Strike

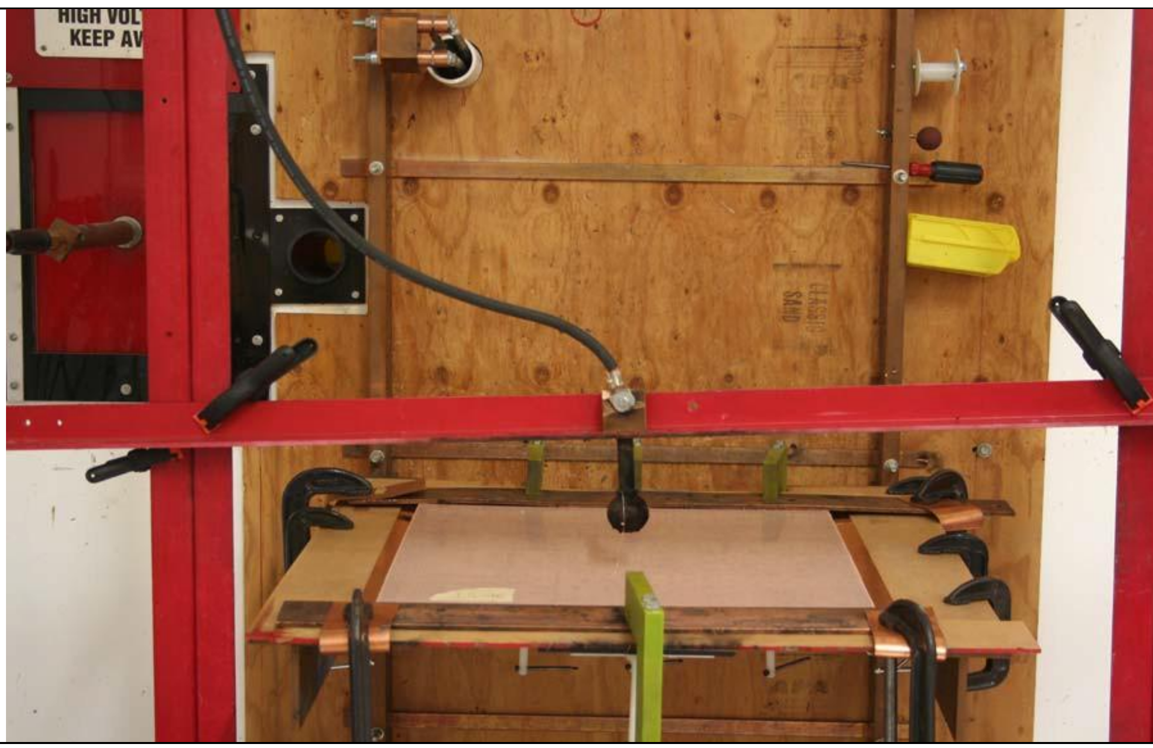


High Current Test – Panel LS-15 Components D, B, C*

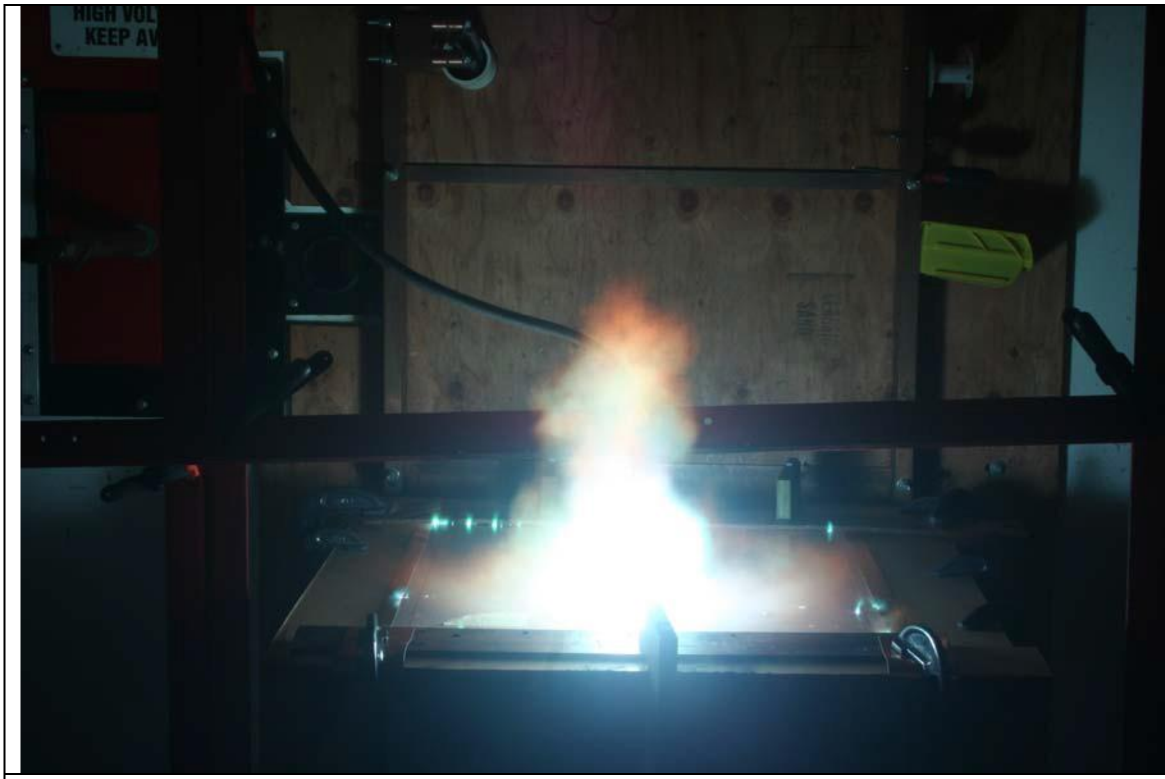
High Current Test – Panel LS-15 Post-Strike Damage



High Current Test – Panel LS-16 Setup



High Current Test – Panel LS-16 Pre-Strike

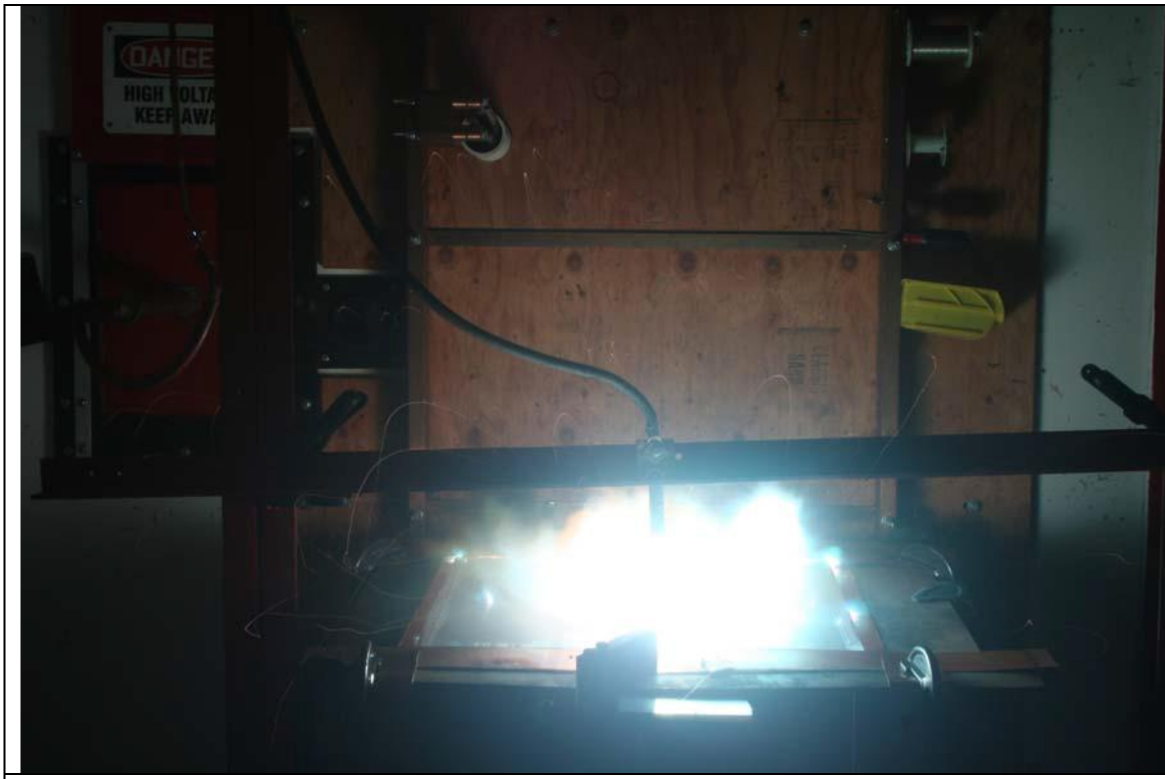


High Current Test – Panel LS-16 Components D, B, C*

High Current Test – Panel LS-16 Post-Strike Damage

High Current Test – Panel LS-18 Setup

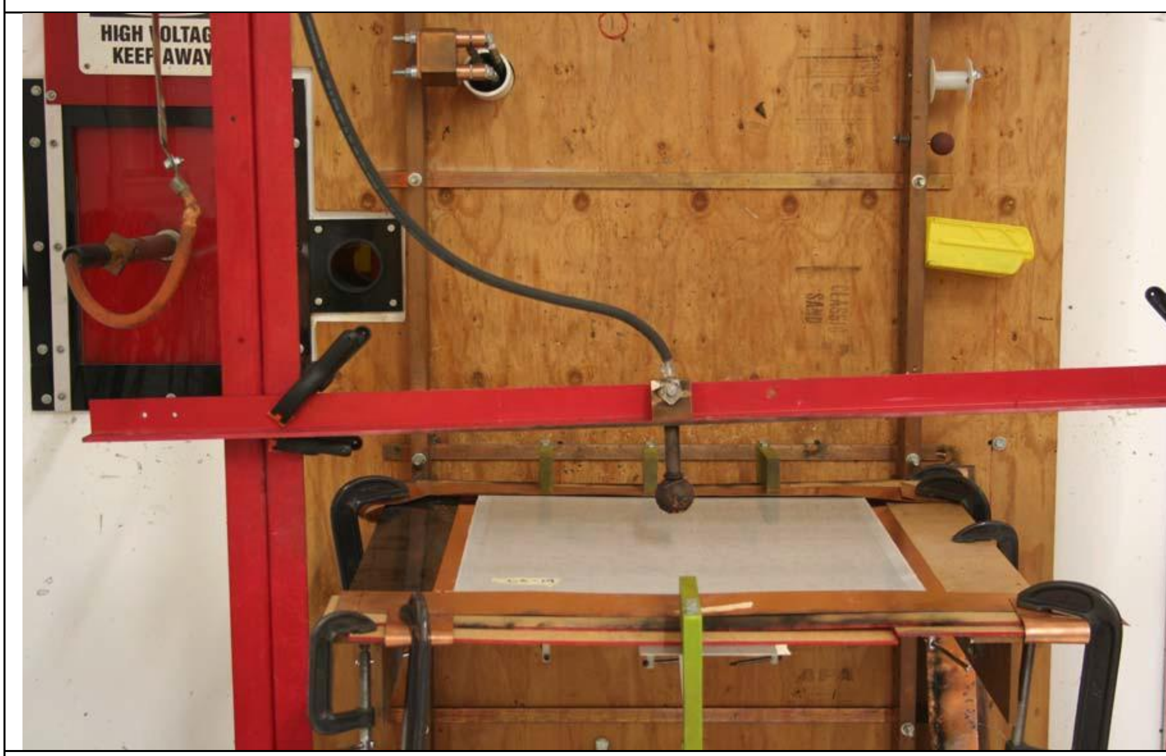
High Current Test – Panel LS-18 Pre-Strike



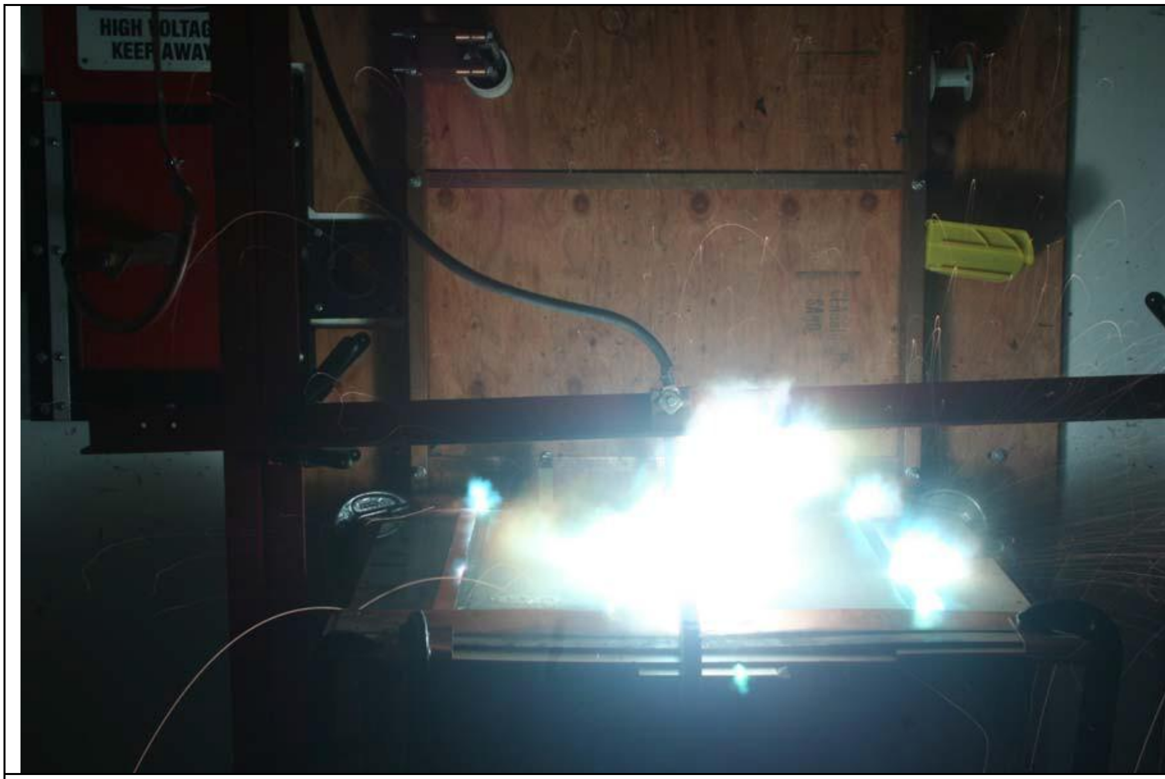
High Current Test – Panel LS-18 Components D, B, C*

High Current Test – Panel LS-18 Post-Strike Damage

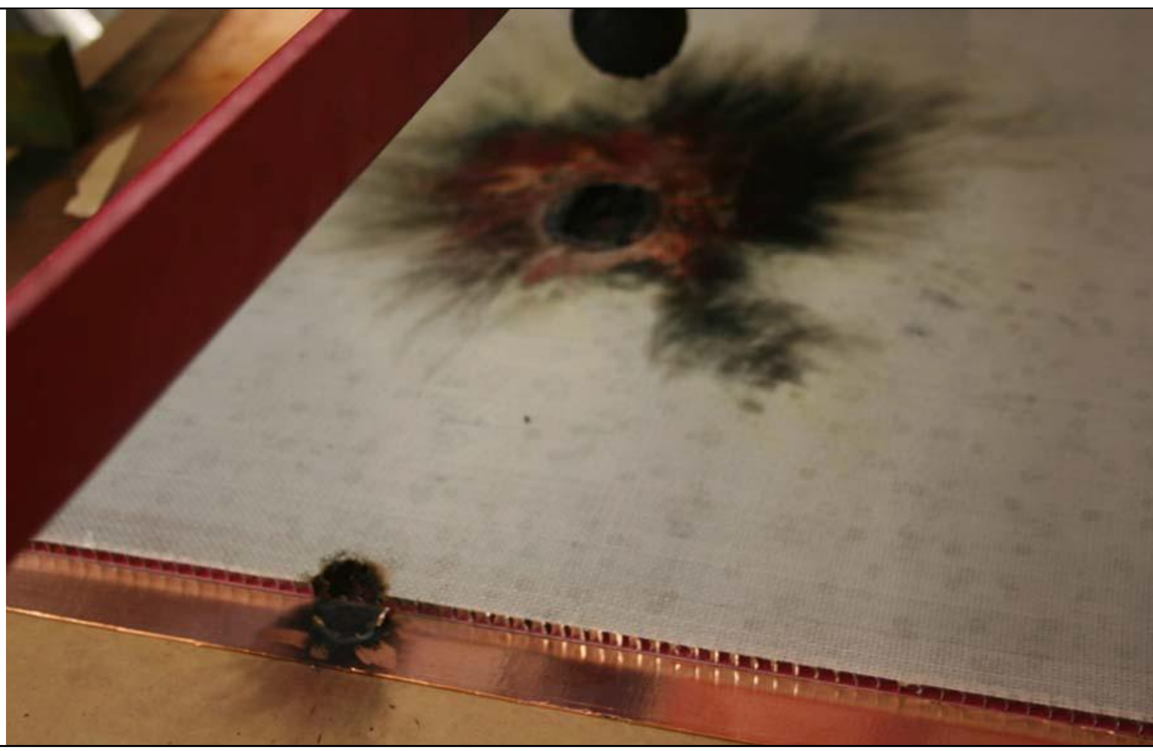
High Current Test – Panel LS-19 Setup



High Current Test – Panel LS-19 Pre-Strike

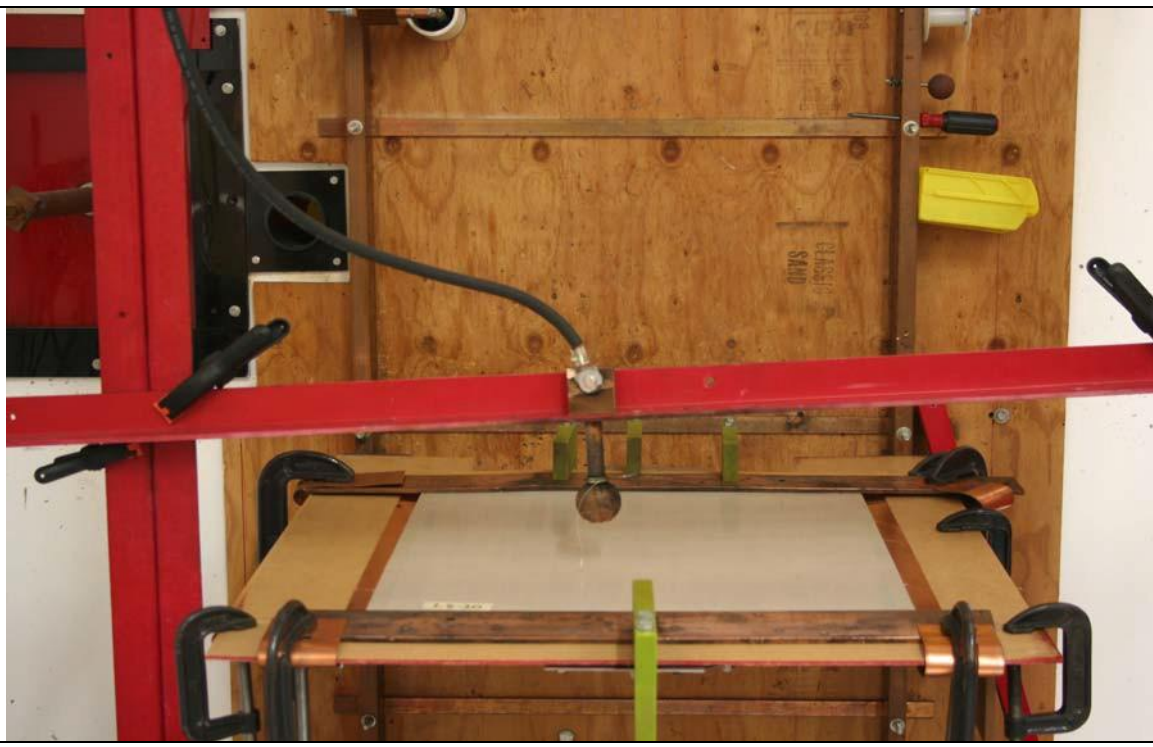


High Current Test – Panel LS-19 Components D, B, C*

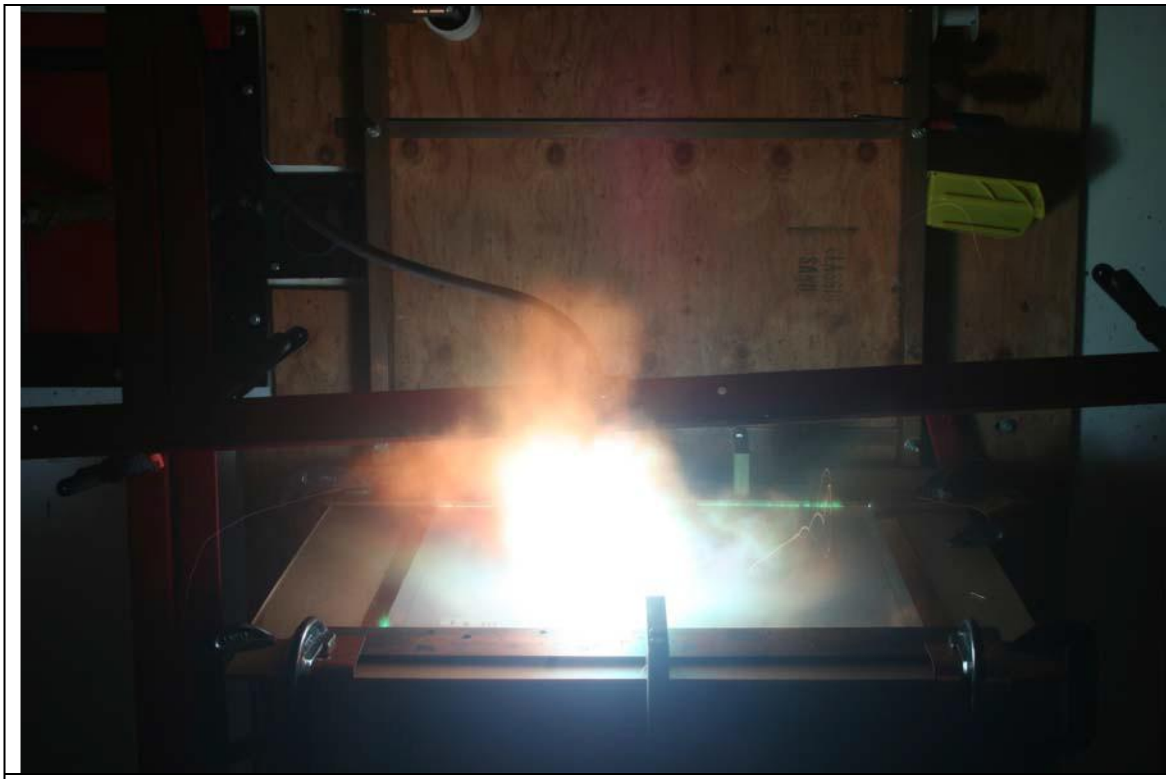


High Current Test – Panel LS-19 Post-Strike Damage

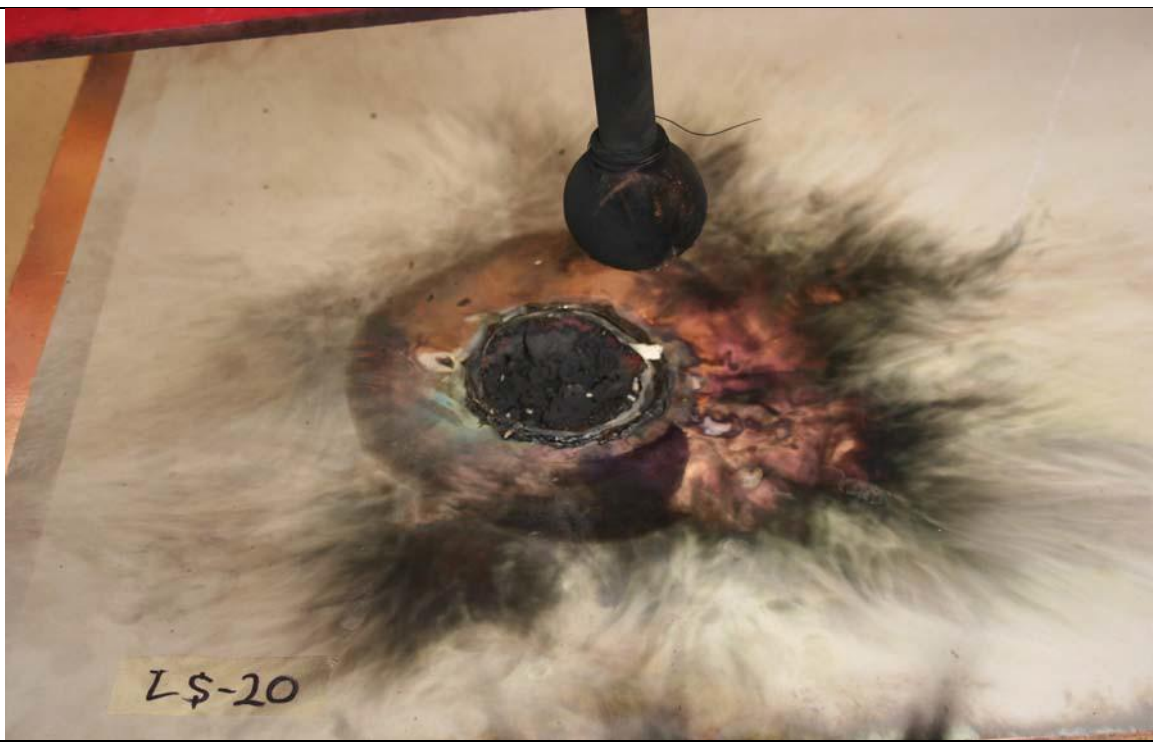
High Current Test – Panel LS-20 Setup



High Current Test – Panel LS-20 Pre-Strike

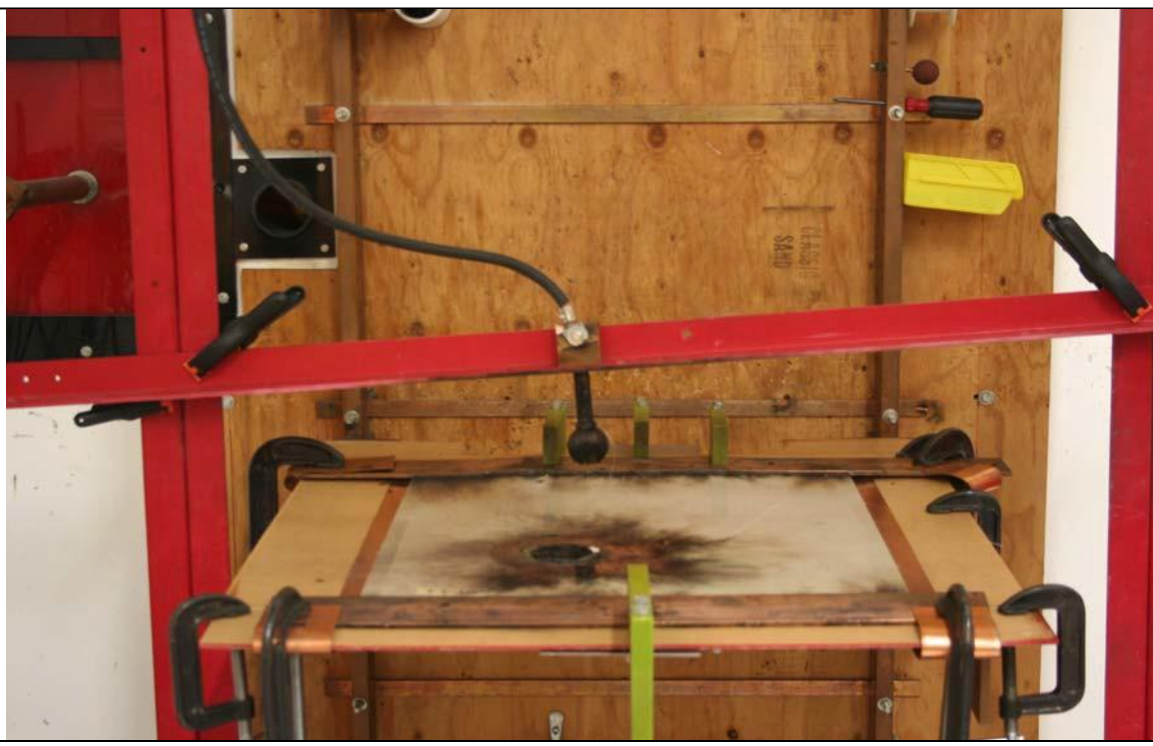


High Current Test – Panel LS-20 Components D, B, C*

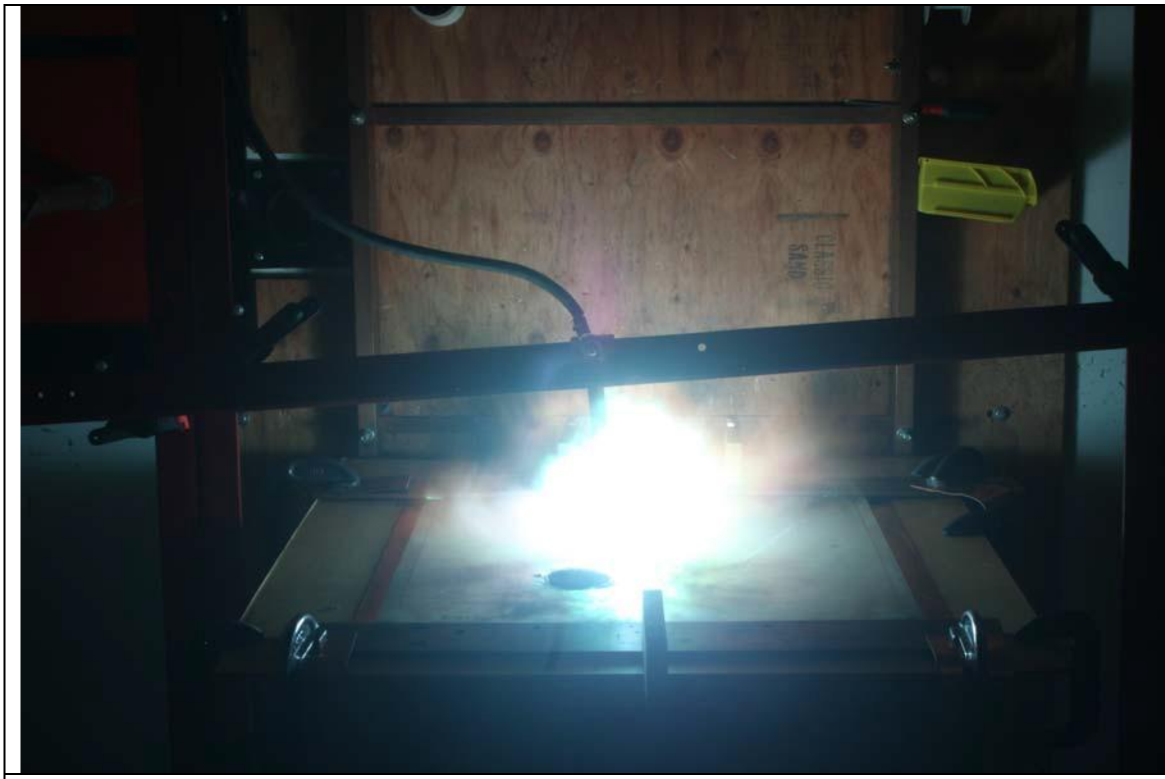


High Current Test – Panel LS-20 Post-Strike Damage

High Current Test – Panel LS-20 Setup

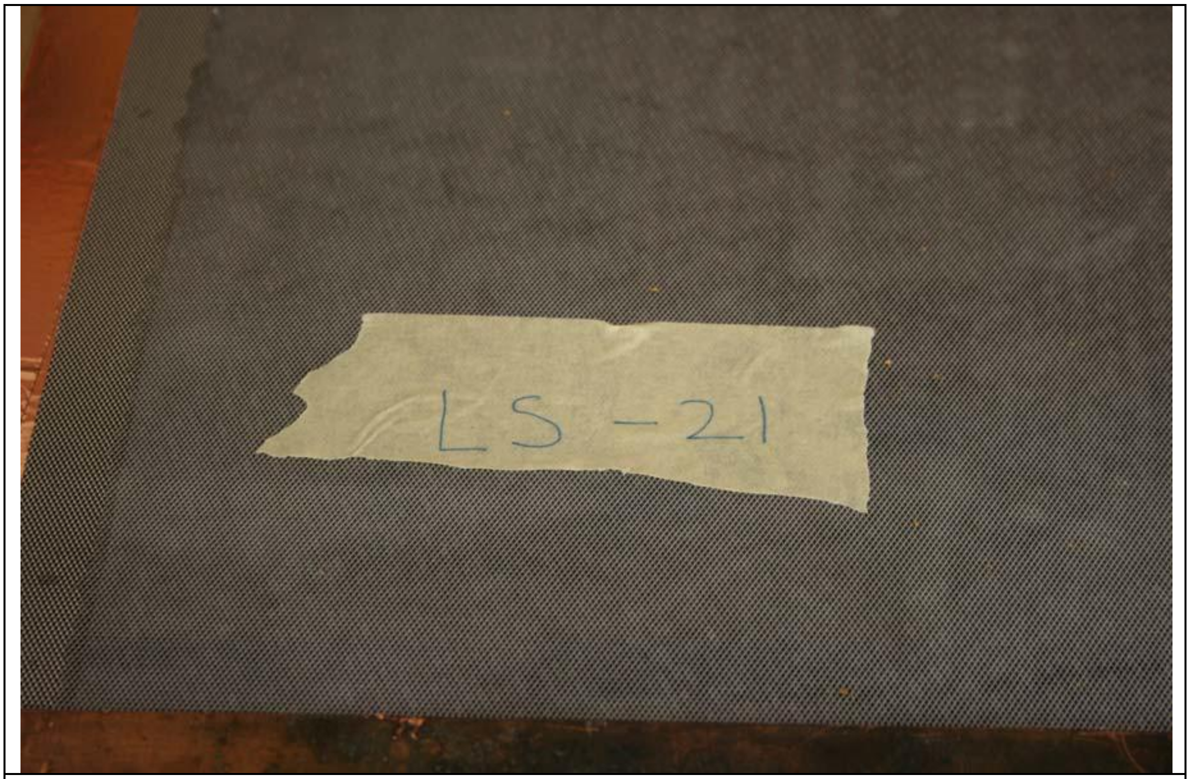


High Current Test – Panel LS-20 Pre-Strike

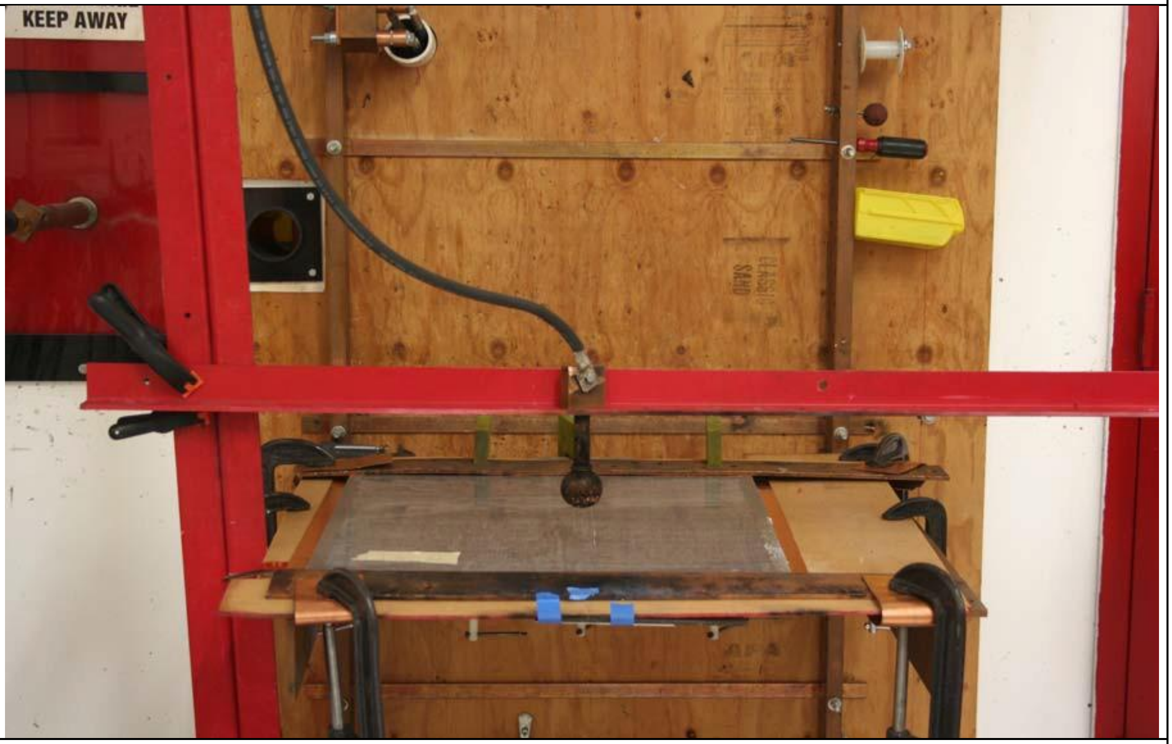


High Current Test – Panel LS-20 Components D, B, C*

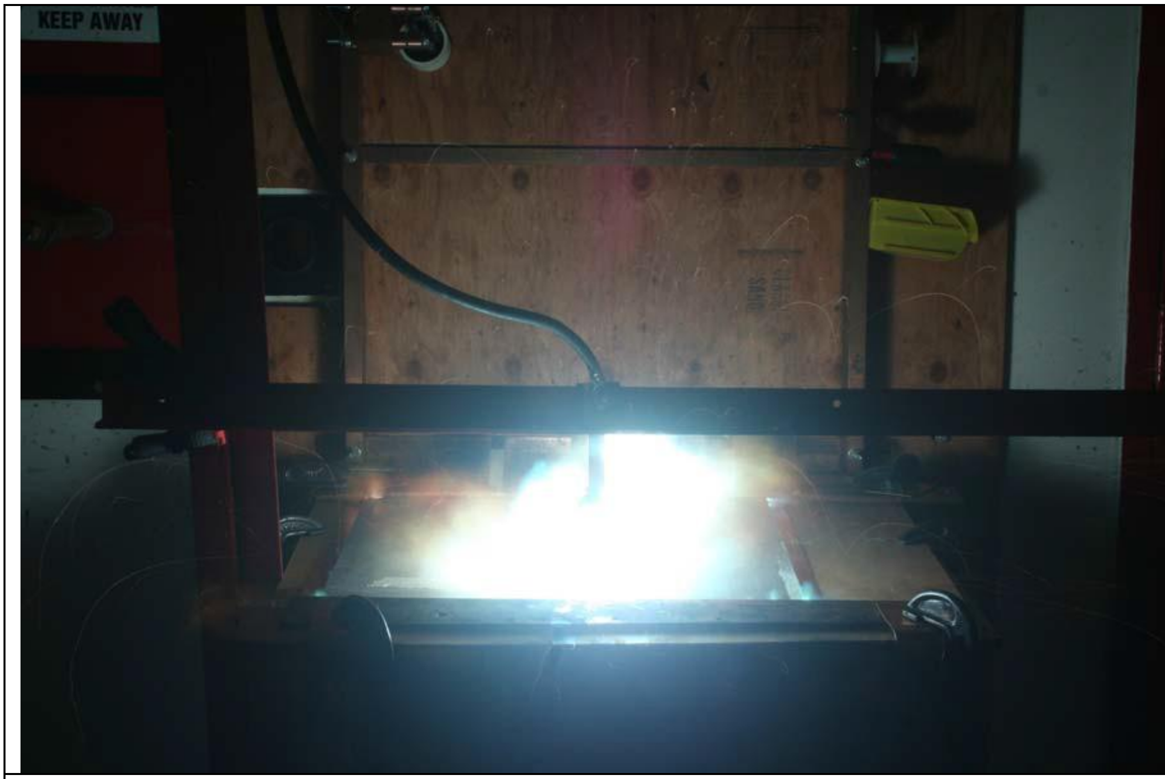
High Current Test – Panel LS-20 Post-Strike Damage



High Current Test – Panel LS-21 Setup

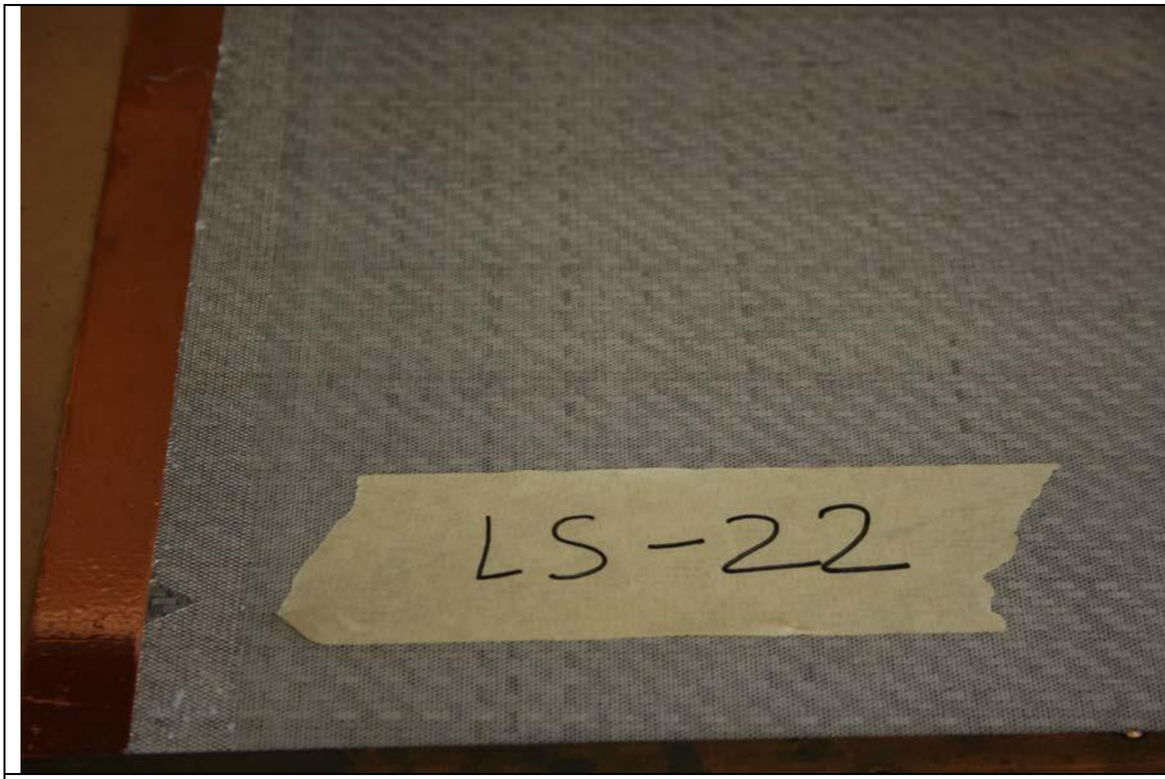


High Current Test – Panel LS-21 Pre-Strike



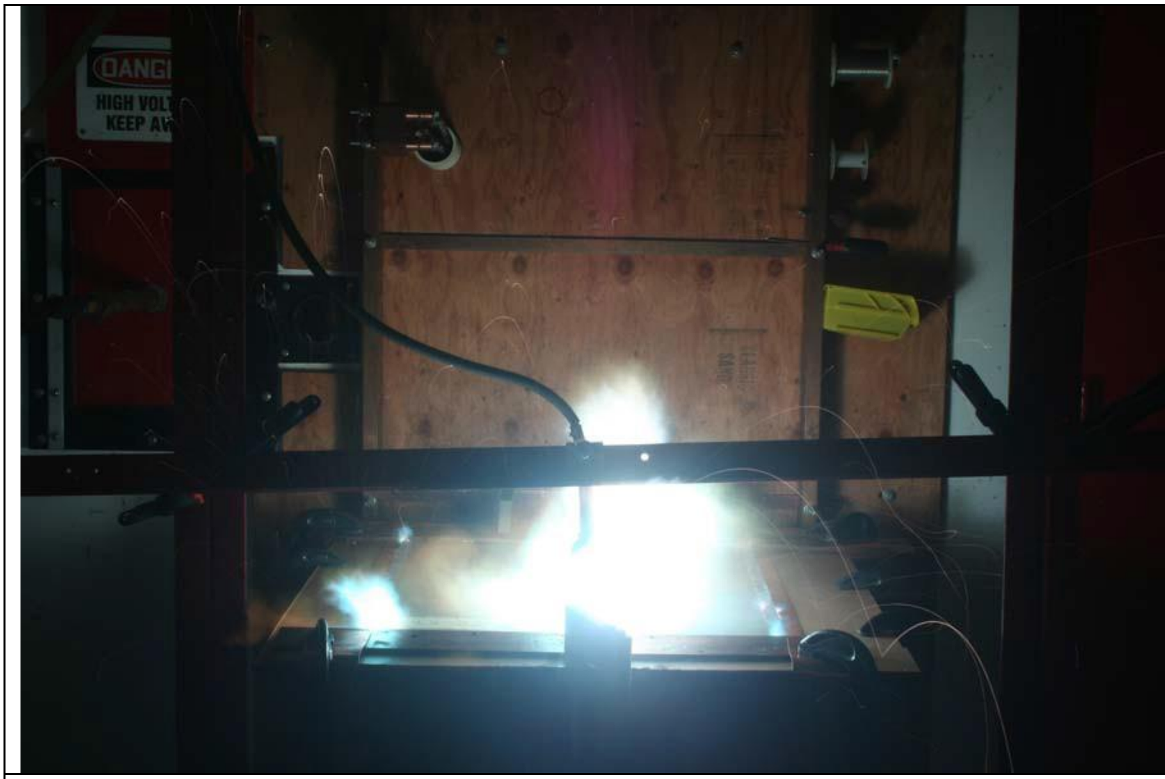
High Current Test – Panel LS-21 Components D, B, C*

High Current Test – Panel LS-21 Post-Strike Damage



High Current Test – Panel LS-22 Setup

High Current Test – Panel LS-22 Pre-Strike

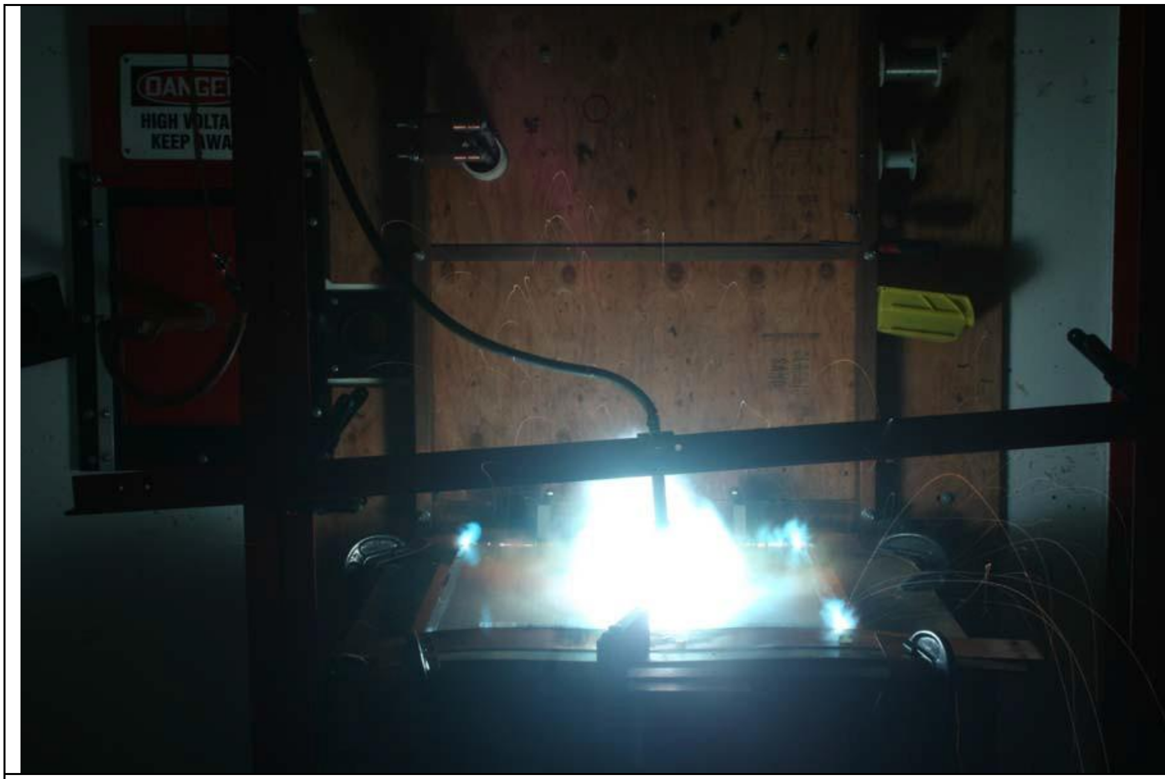


High Current Test – Panel LS-22 Components D, B, C*

High Current Test – Panel LS-22 Post-Strike Damage

High Current Test – Panel LS-23 Setup

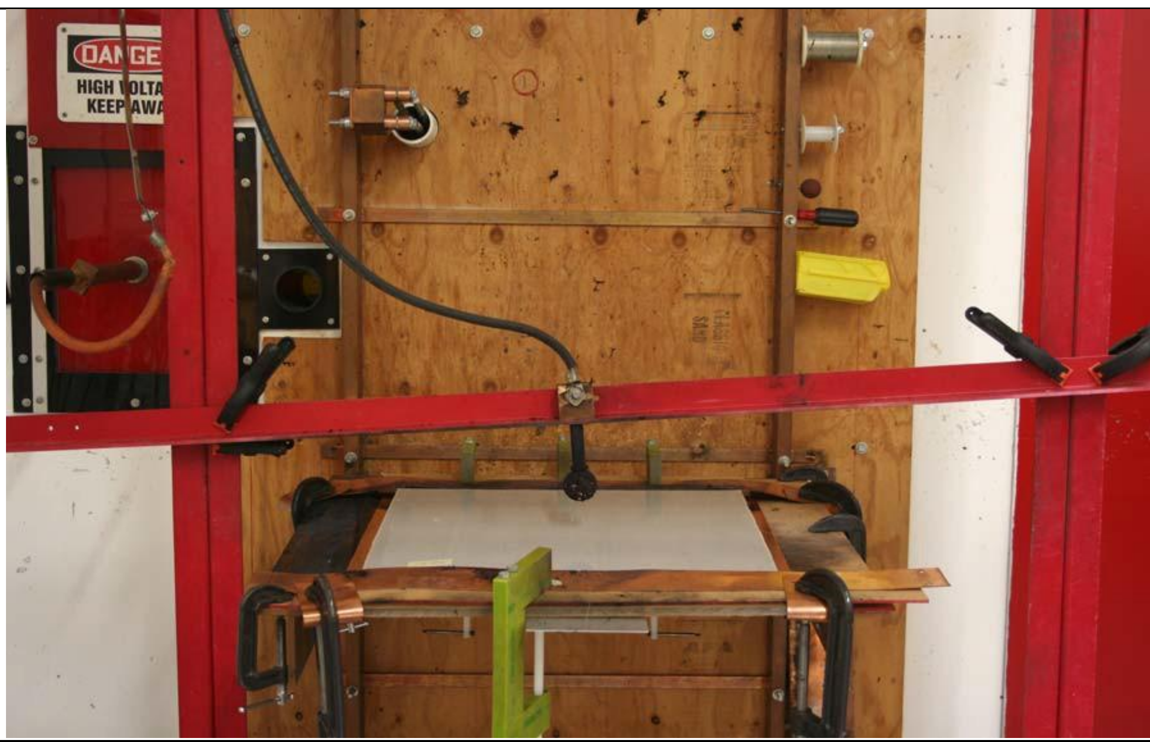
High Current Test – Panel LS-23 Pre-Strike



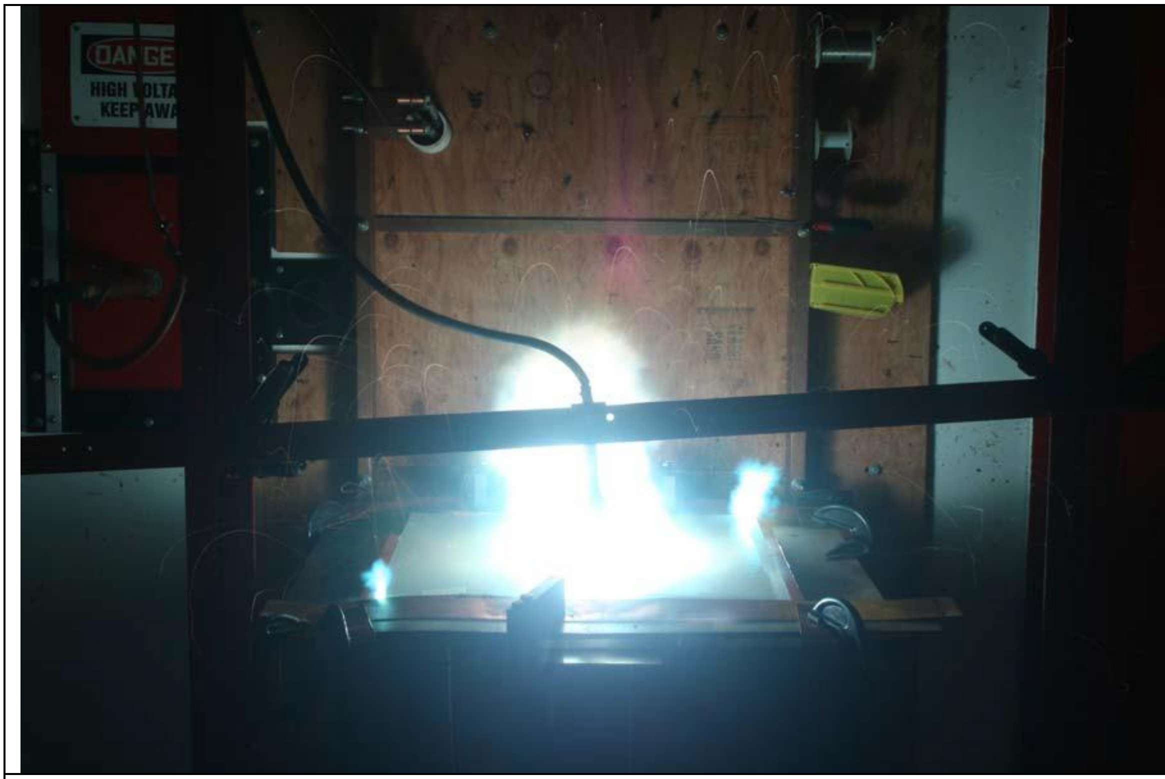
High Current Test – Panel LS-23 Components D, B, C*

High Current Test – Panel LS-23 Post-Strike Damage

High Current Test – Panel LS-24 Setup

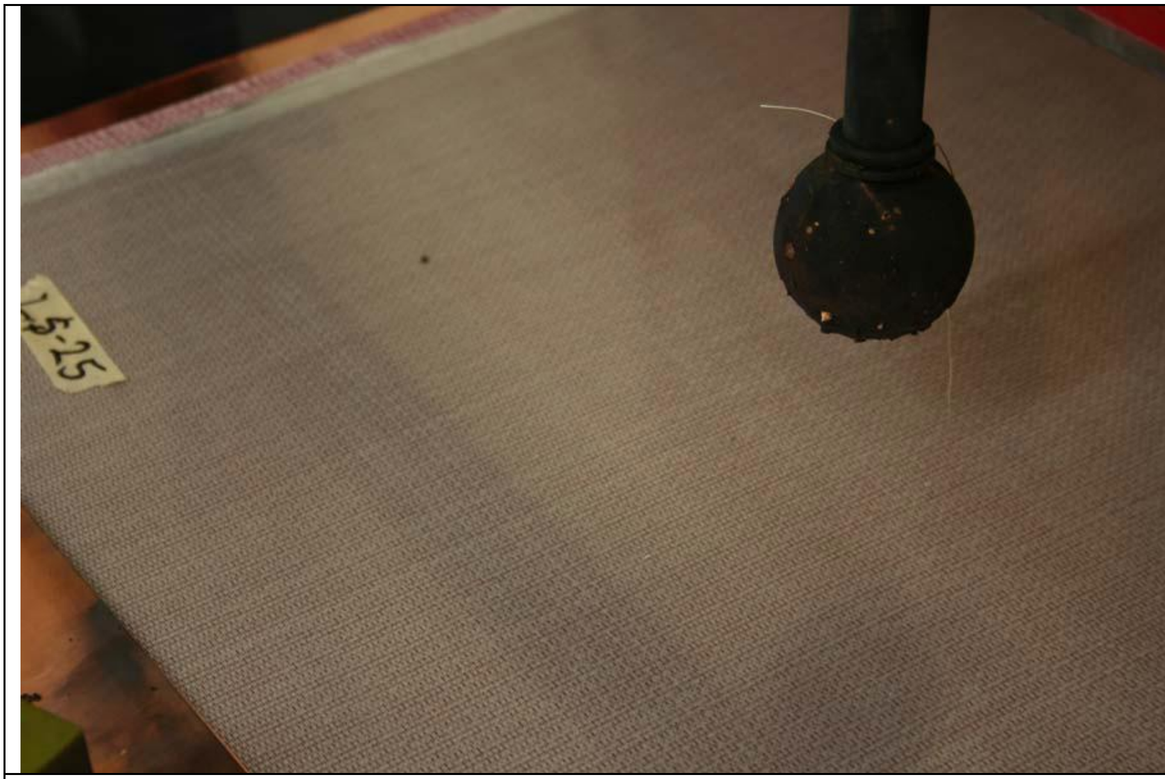


High Current Test – Panel LS-24 Pre-Strike



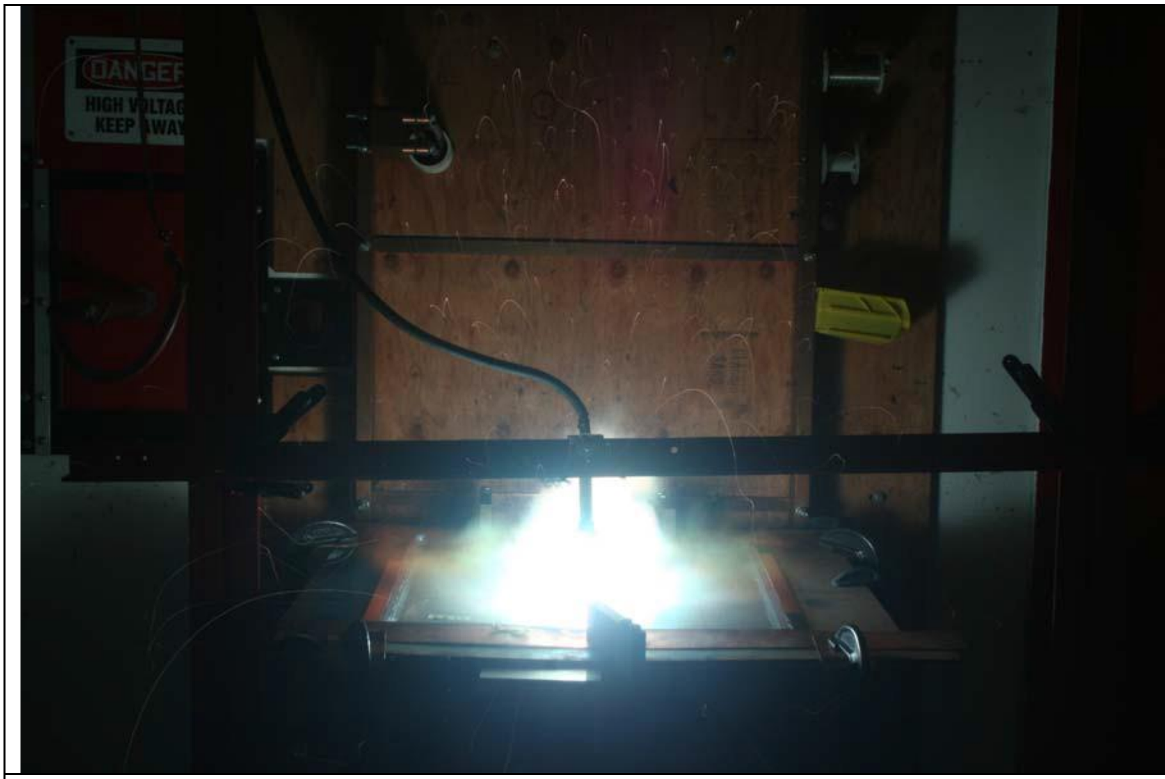
High Current Test – Panel LS-24 Components D, B, C*

High Current Test – Panel LS-24 Post-Strike Damage



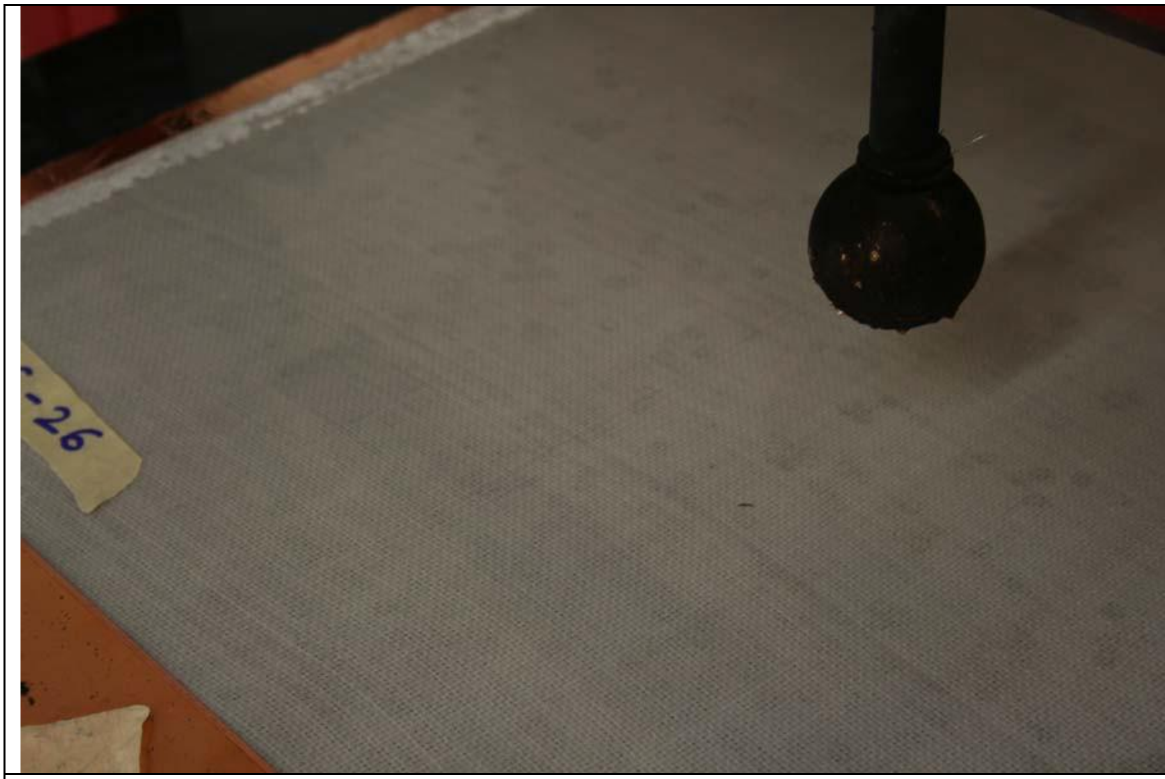
High Current Test – Panel LS-25 Setup

High Current Test – Panel LS-25 Pre-Strike



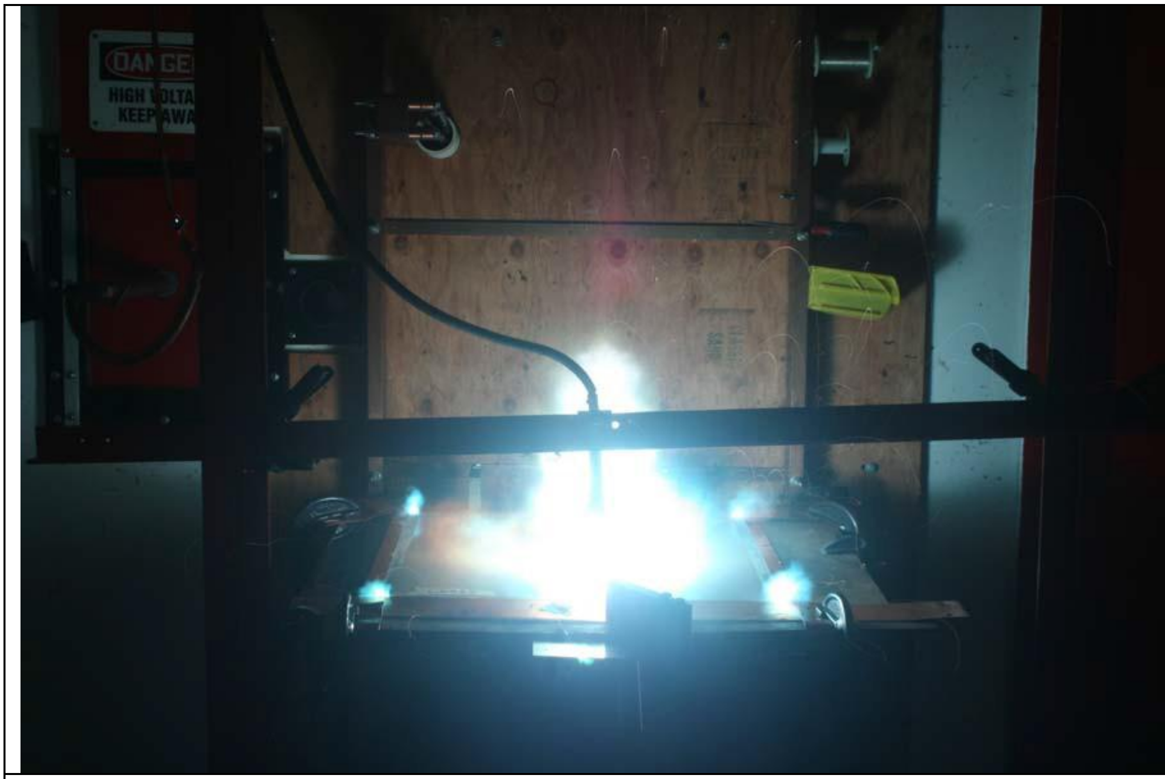
High Current Test – Panel LS-25 Components D, B, C*

High Current Test – Panel LS-25 Post-Strike Damage

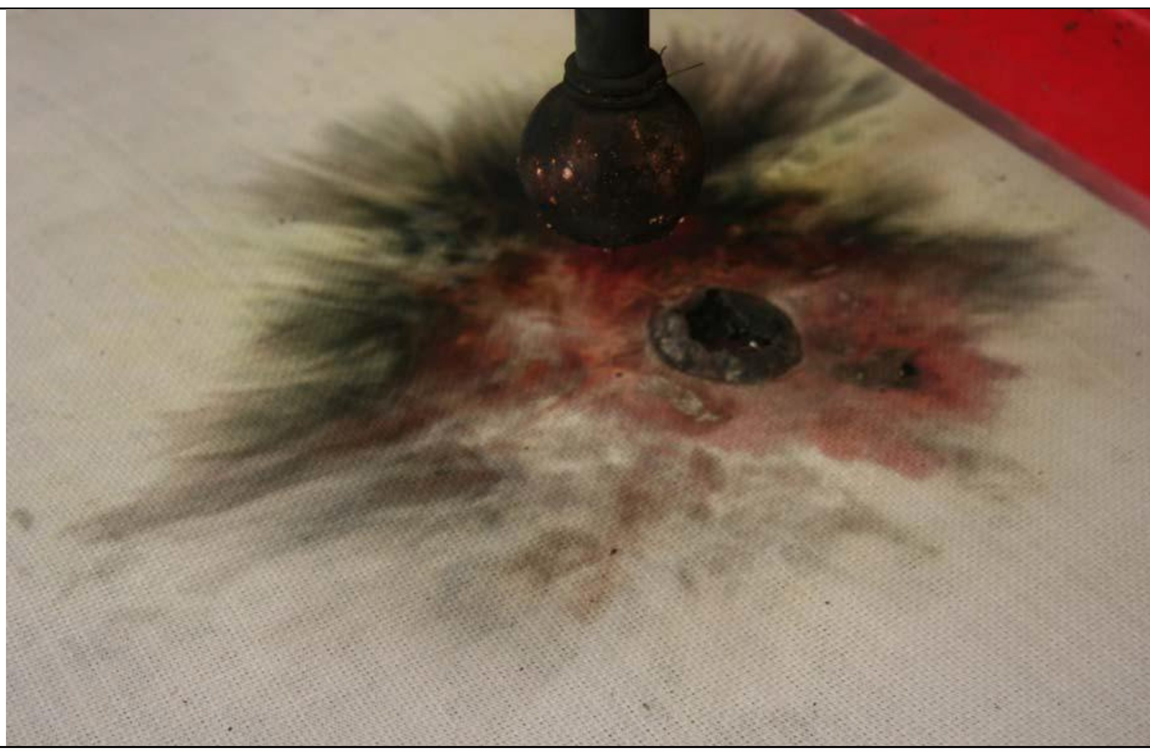


High Current Test – Panel LS-26 Setup

High Current Test – Panel LS-26 Pre-Strike

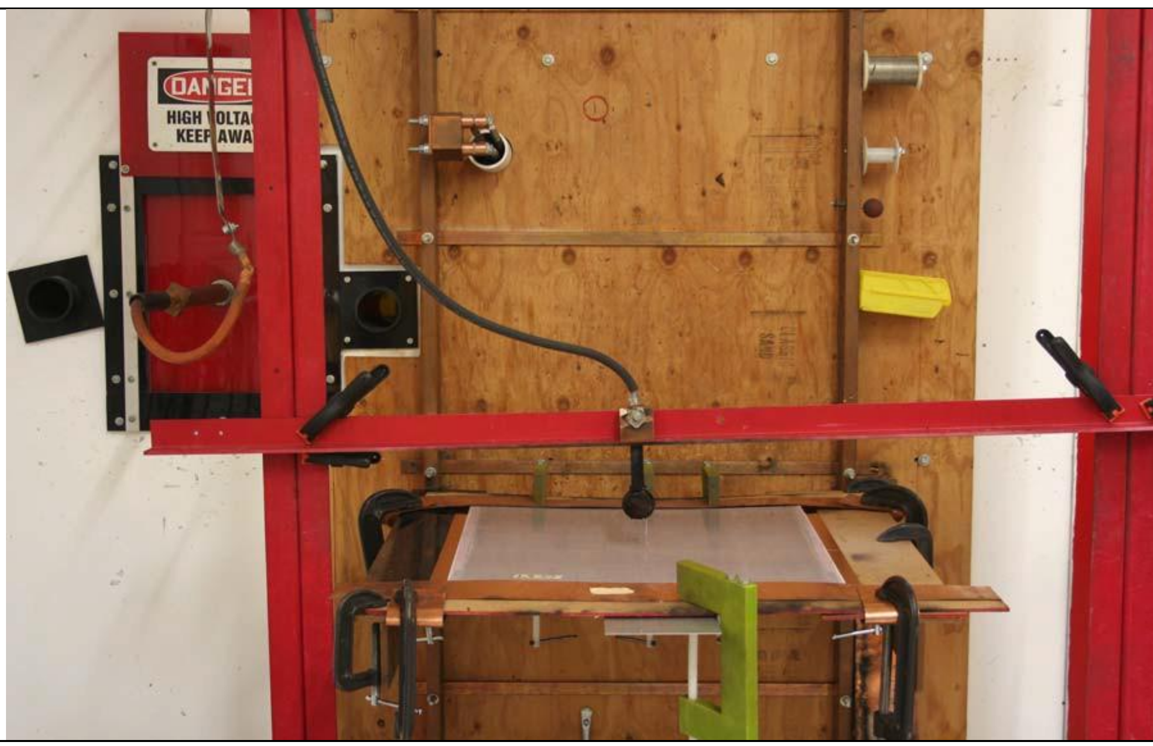


High Current Test – Panel LS-26 Components D, B, C*

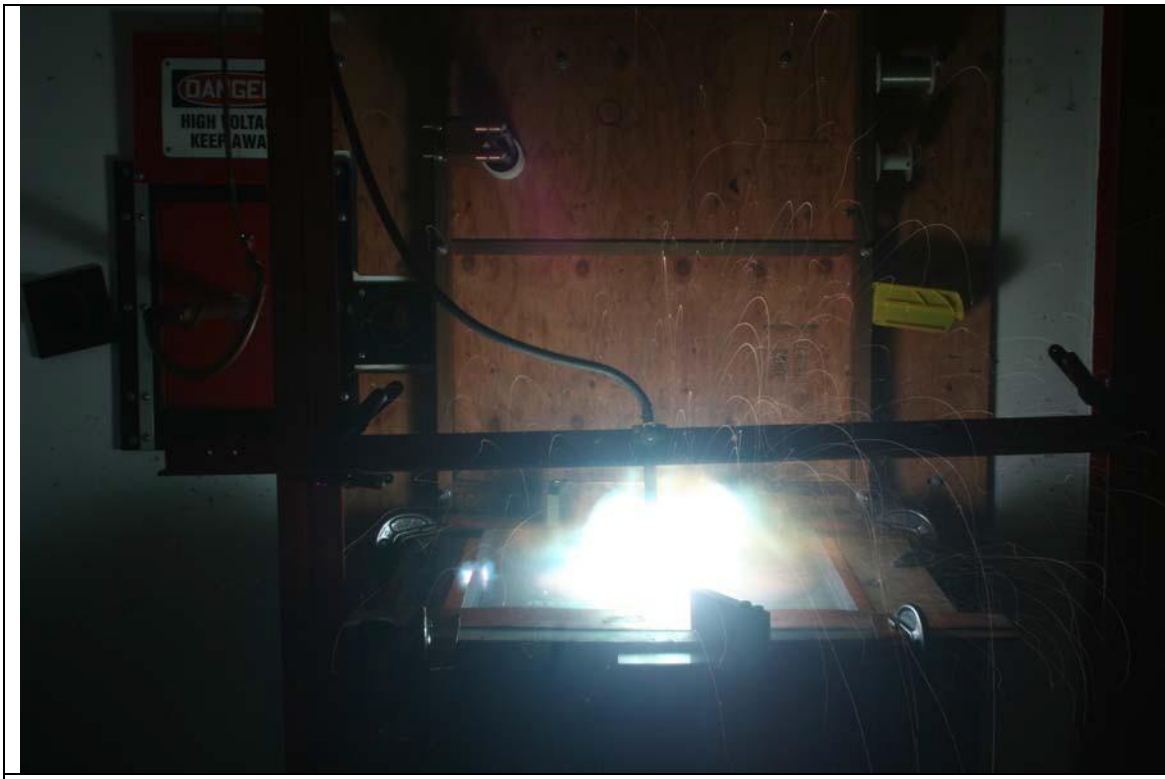


High Current Test – Panel LS-26 Post-Strike Damage

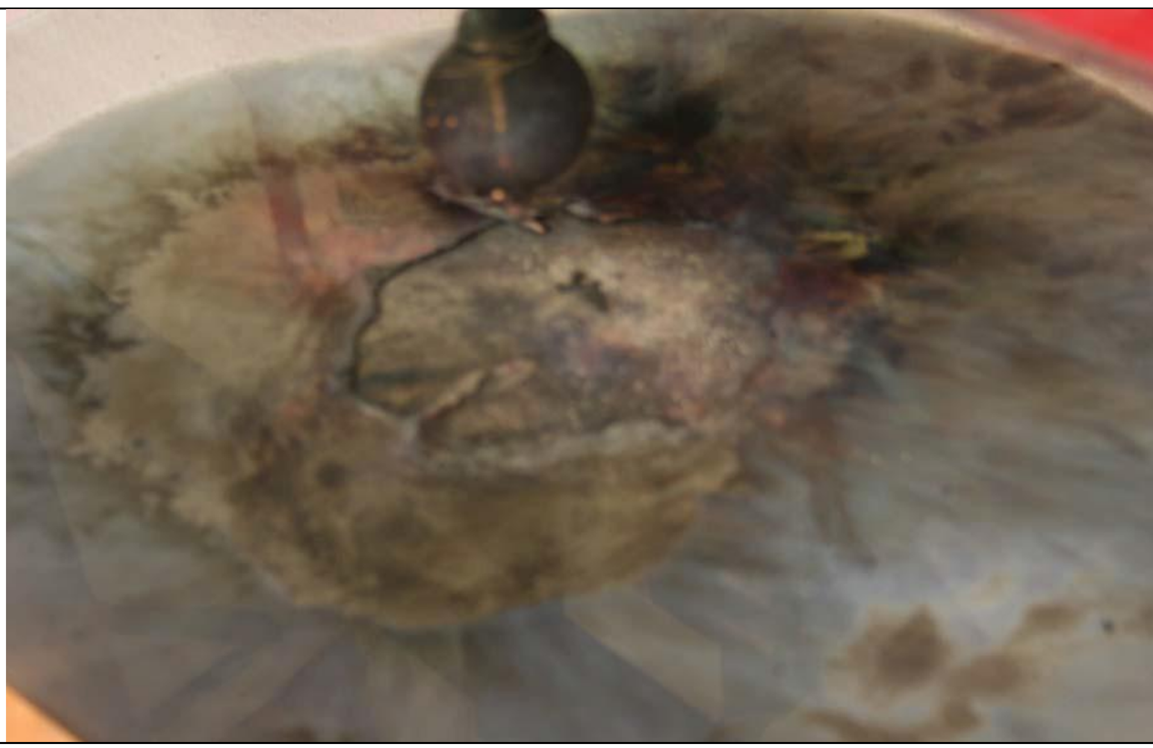
High Current Test – Panel LS-27 Setup



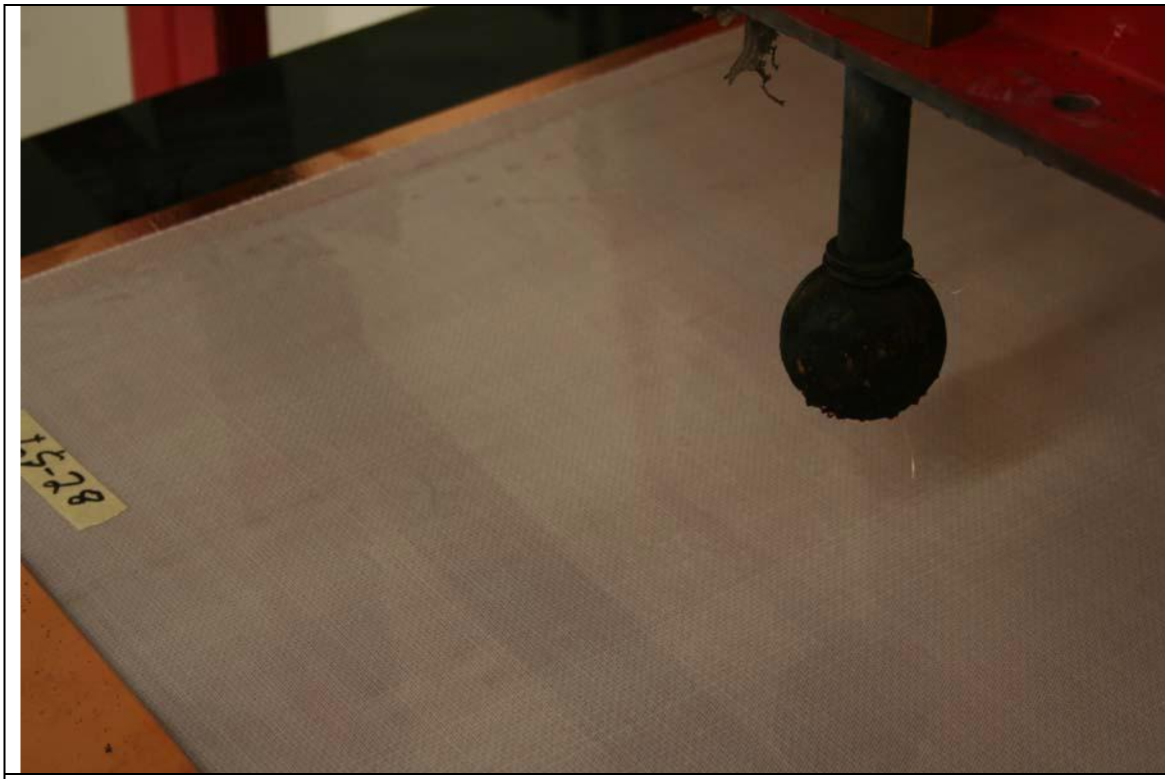
High Current Test – Panel LS-27 Pre-Strike



High Current Test – Panel LS-27 Components D, B, C*

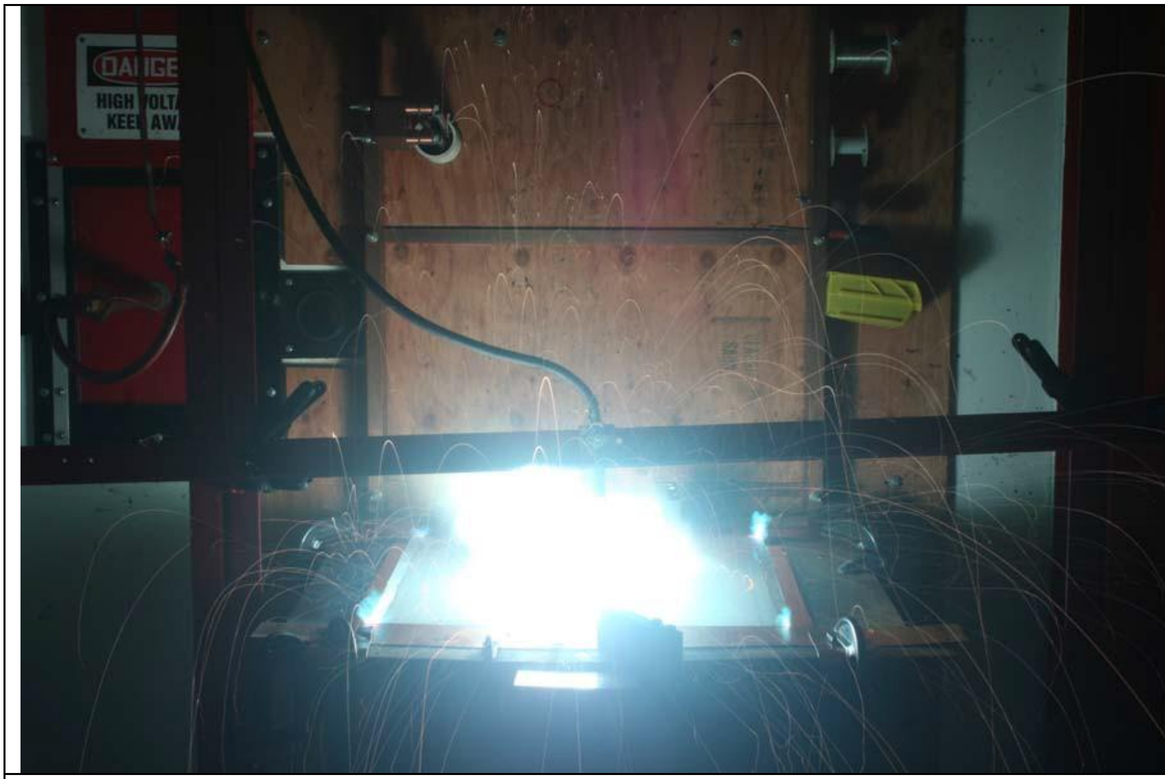


High Current Test – Panel LS-27 Post-Strike Damage



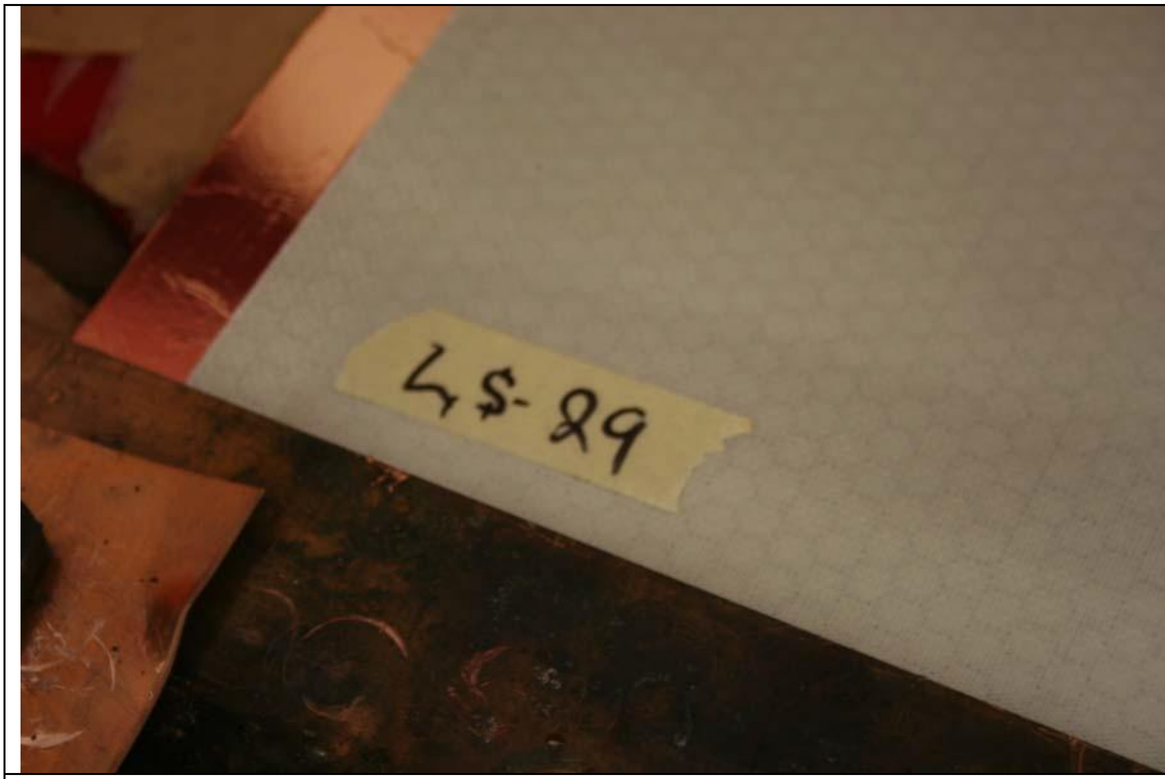
High Current Test – Panel LS-28 Setup

High Current Test – Panel LS-28 Pre-Strike



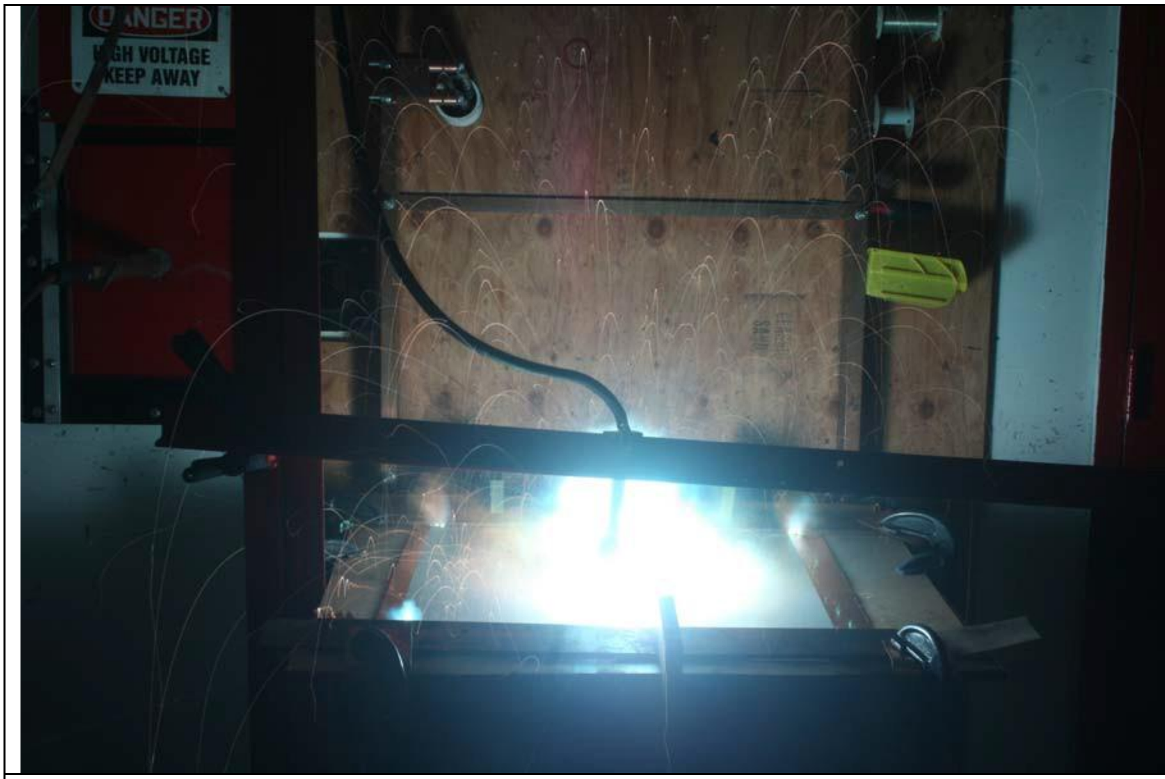
High Current Test – Panel LS-28 Components D, B, C*

High Current Test – Panel LS-28 Post-Strike Damage

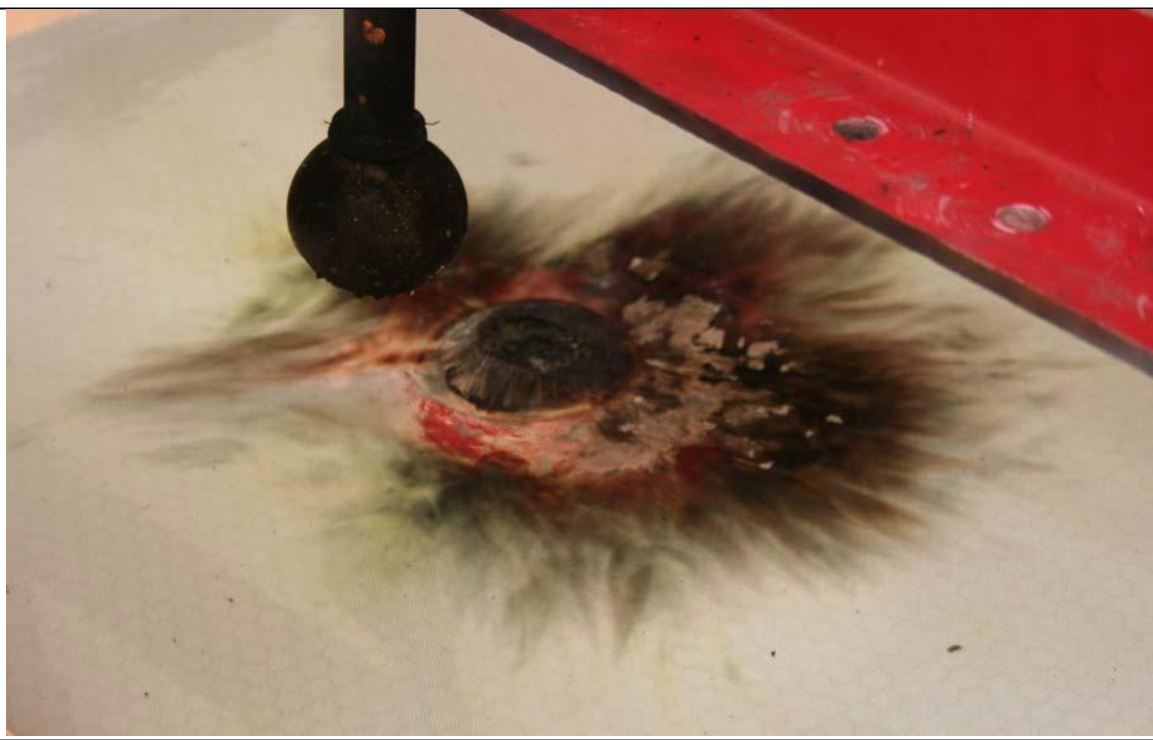


High Current Test – Panel LS-29 Setup

High Current Test – Panel LS-29 Pre-Strike

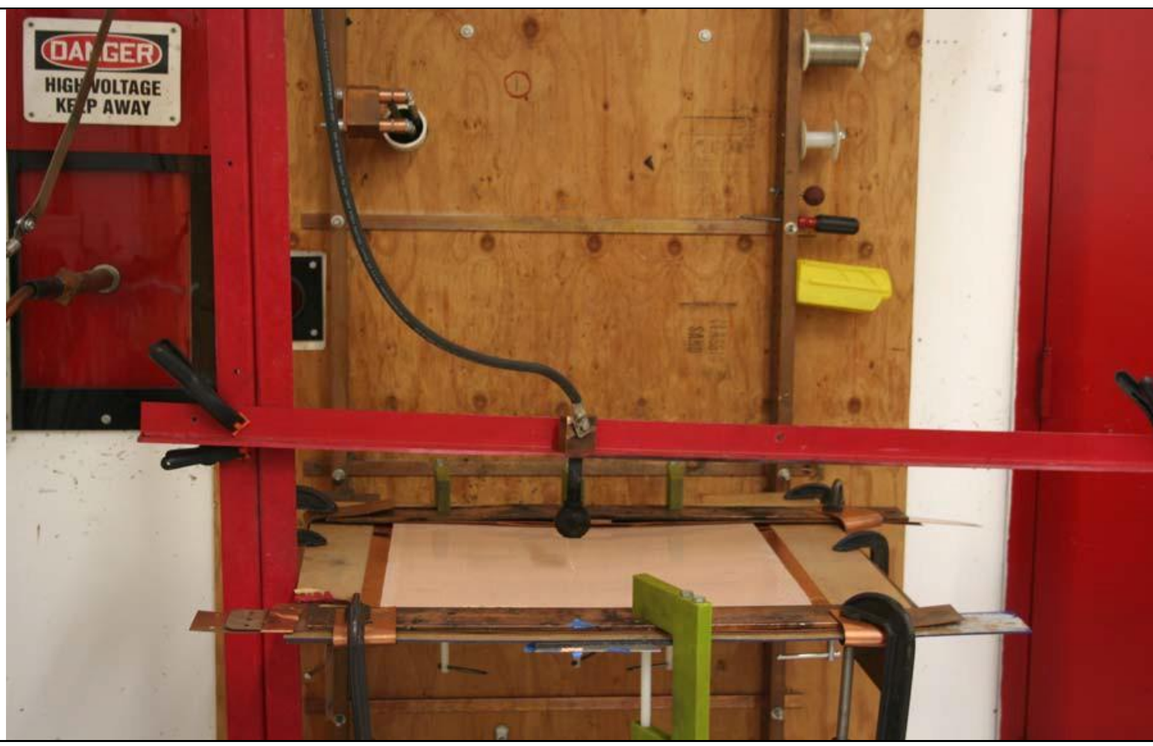


High Current Test – Panel LS-29 Components D, B, C*

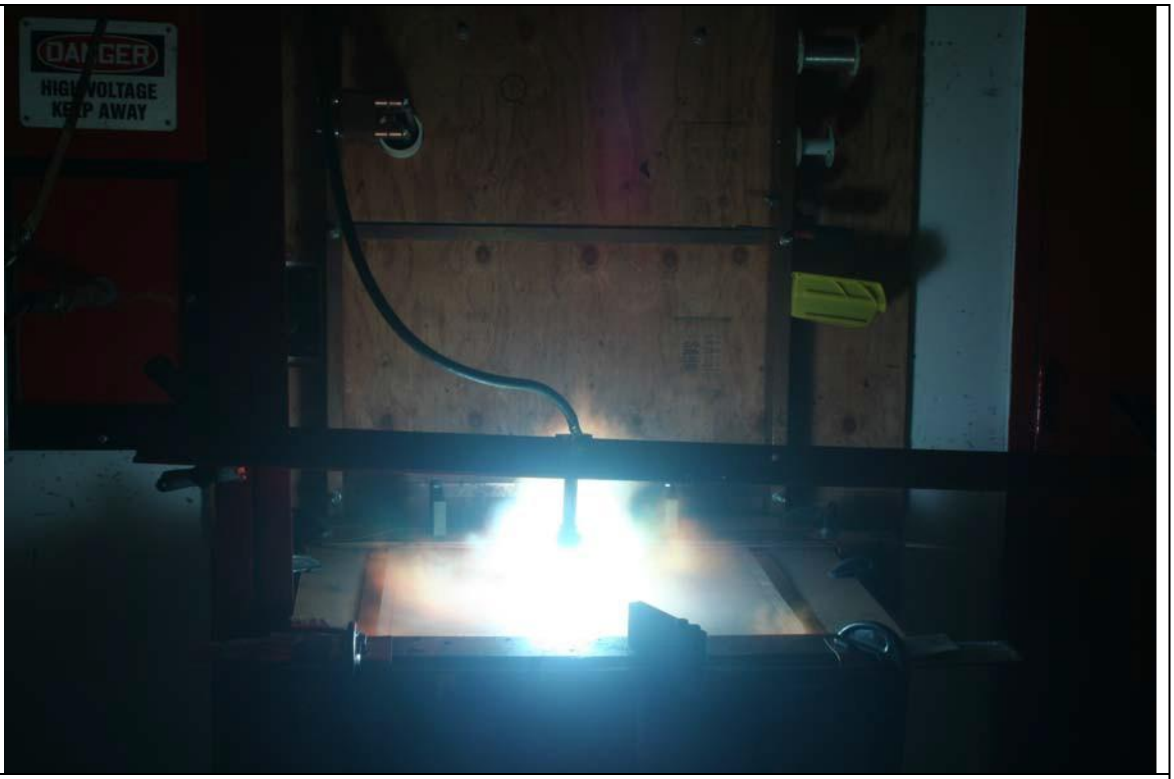


High Current Test – Panel LS-29 Post-Strike Damage

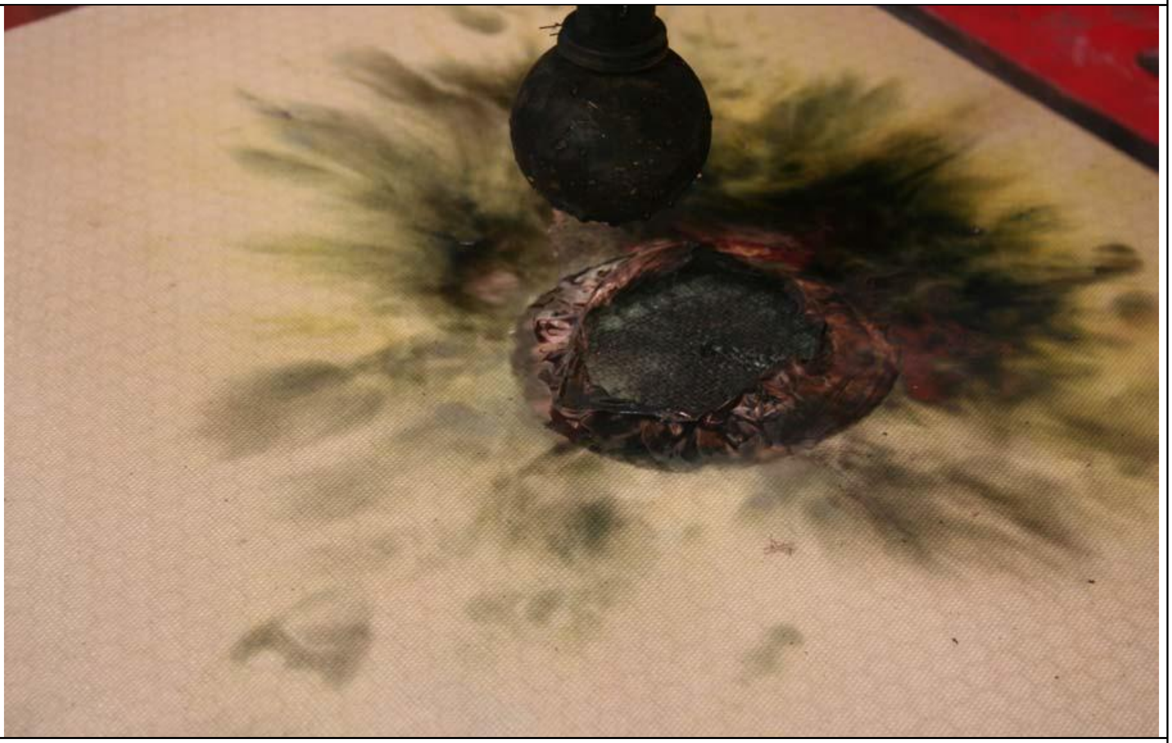
High Current Test – Panel LS-30 Setup



High Current Test – Panel LS-30 Pre-Strike

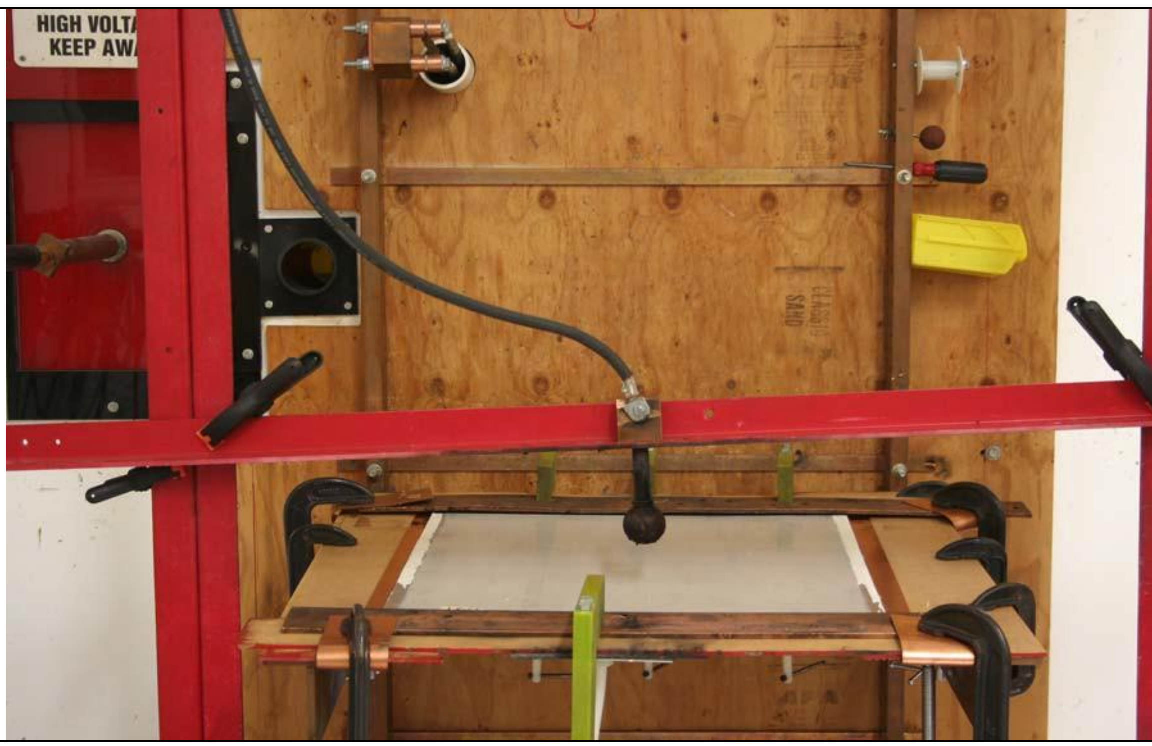


High Current Test – Panel LS-30 Components D, B, C*

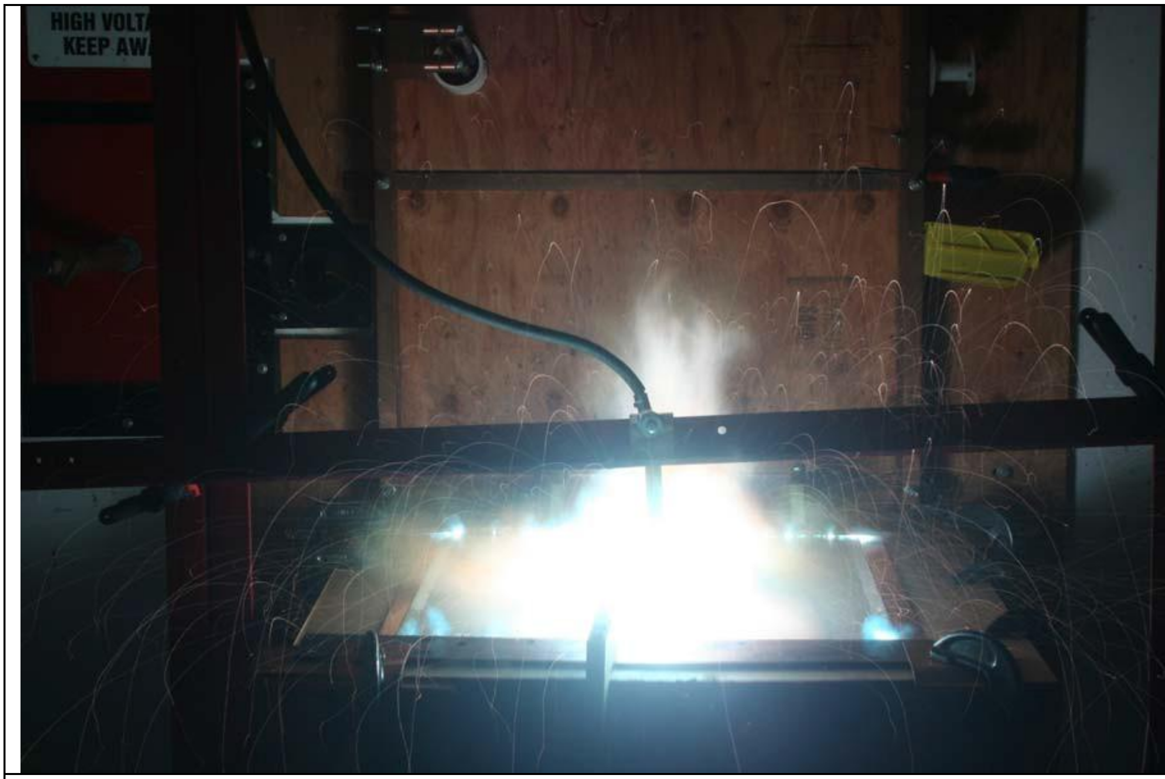


High Current Test – Panel LS-30 Post-Strike Damage

High Current Test – Panel LS-32 Setup

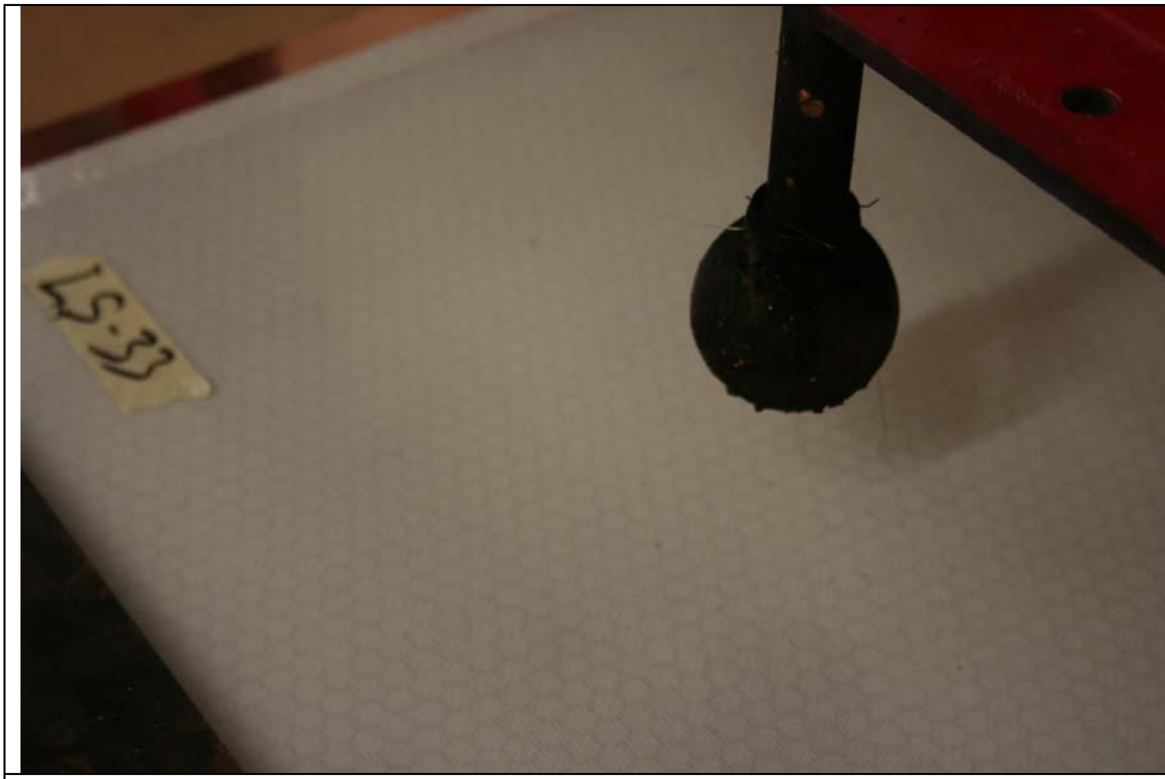


High Current Test – Panel LS-32 Pre-Strike

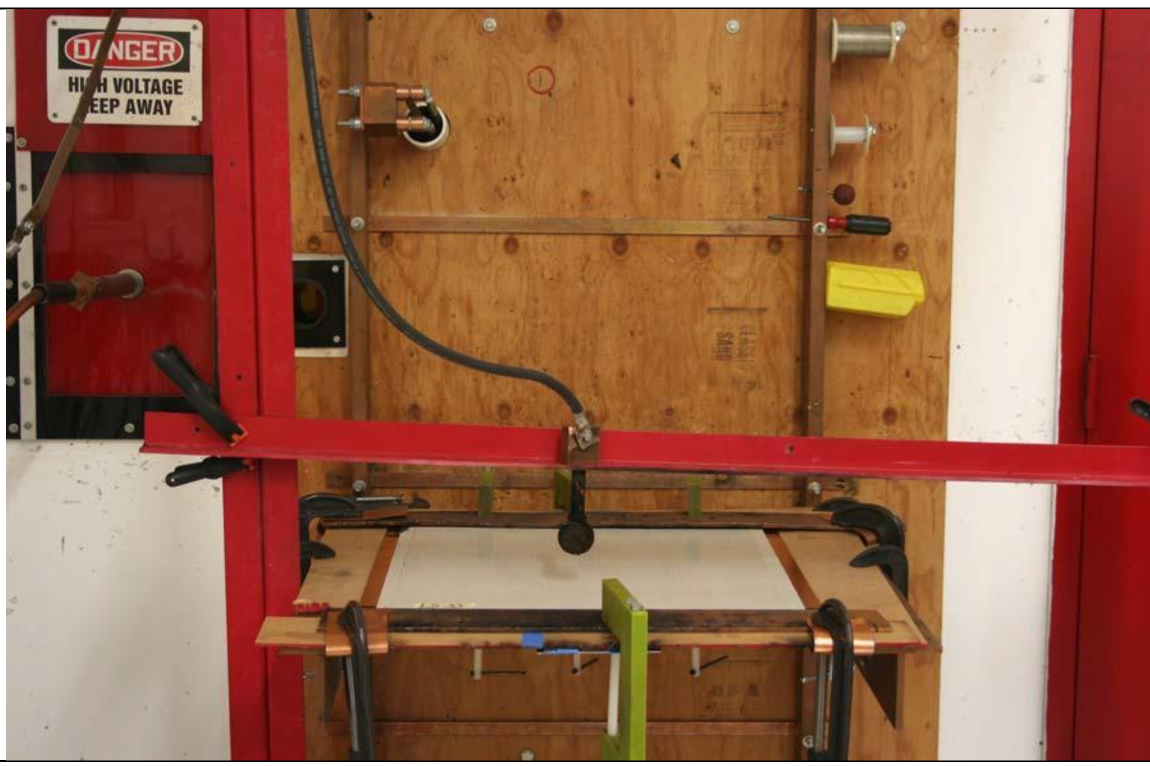


High Current Test – Panel LS-32 Components D, B, C*

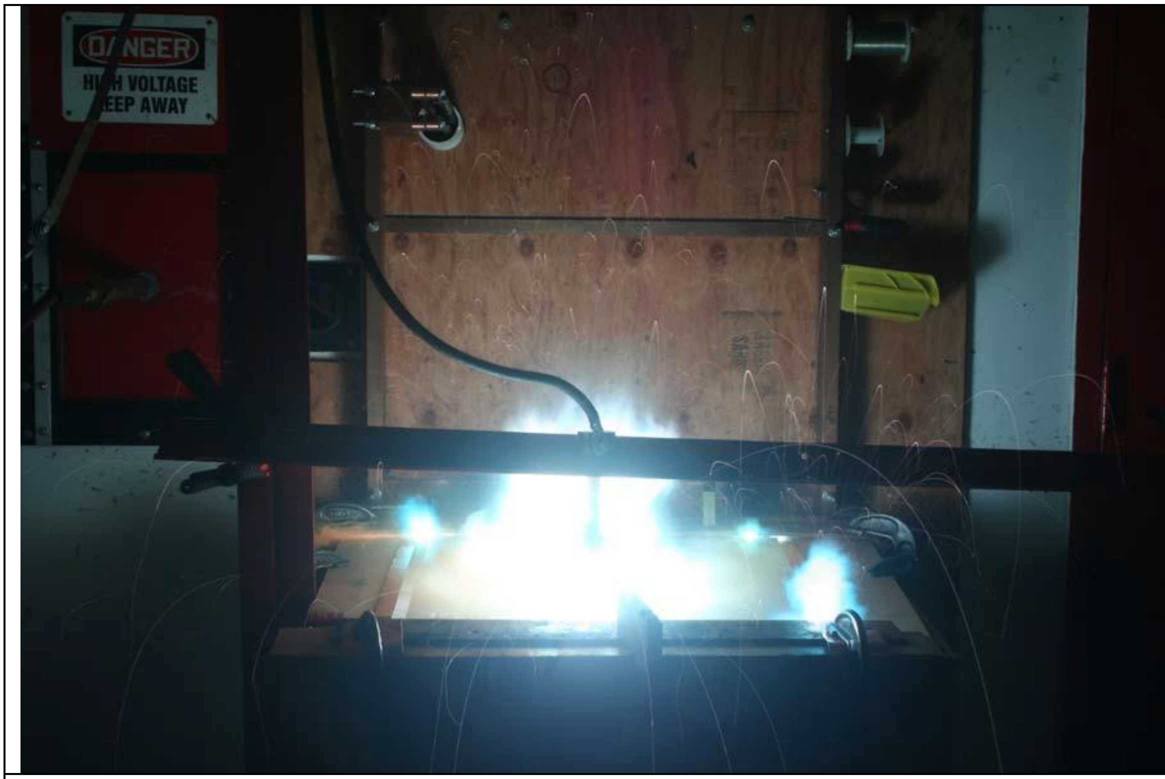
High Current Test – Panel LS-32 Post-Strike Damage



High Current Test – Panel LS- 33Setup



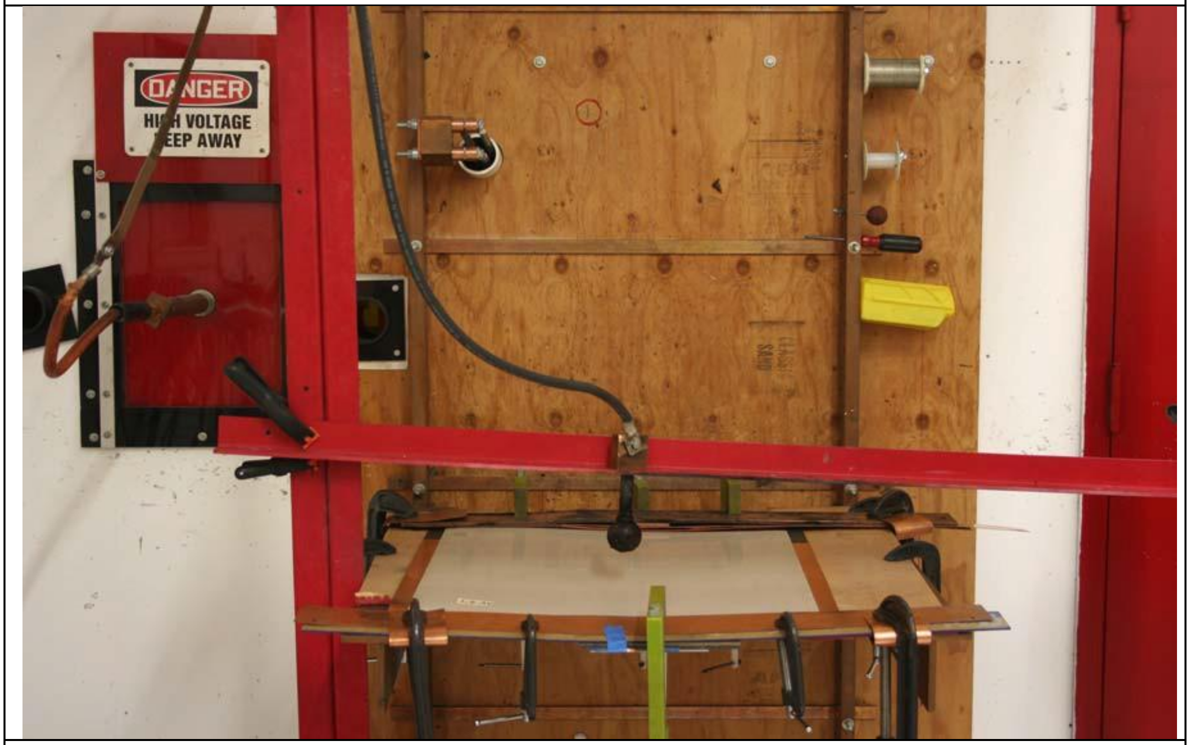
High Current Test – Panel LS-33 Pre-Strike



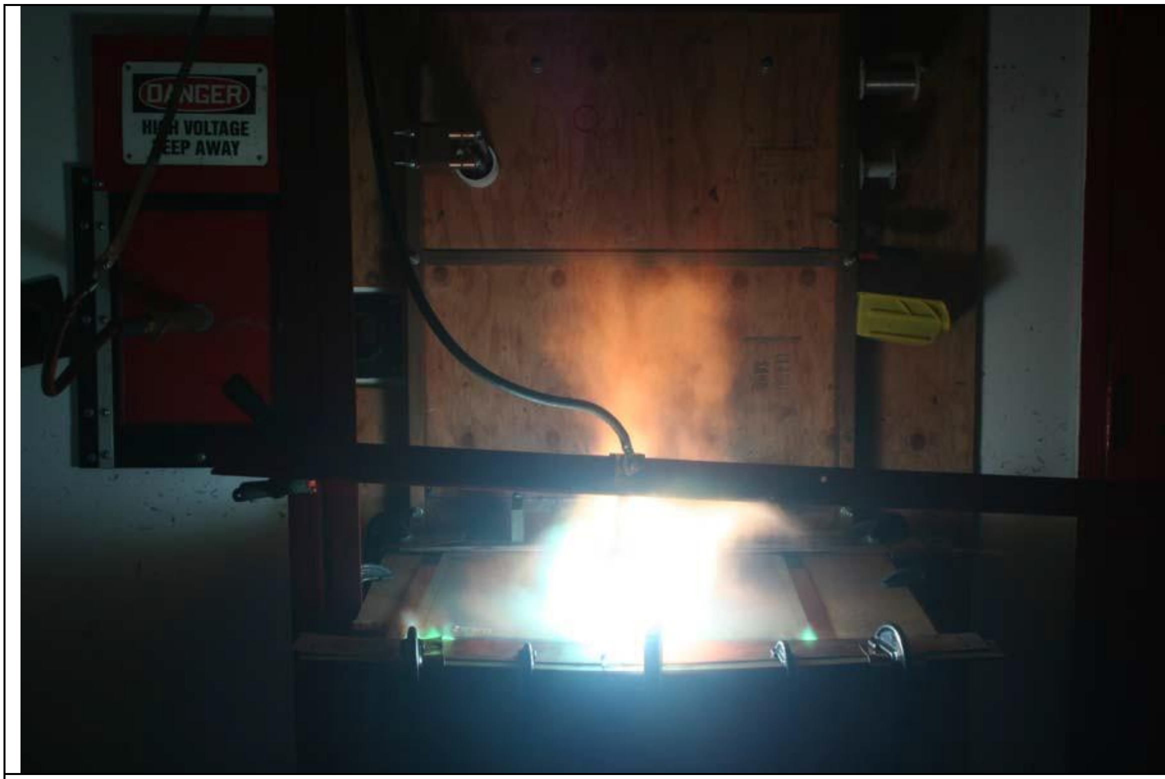
High Current Test – Panel LS-33 Components D, B, C*

High Current Test – Panel LS-33 Post-Strike Damage

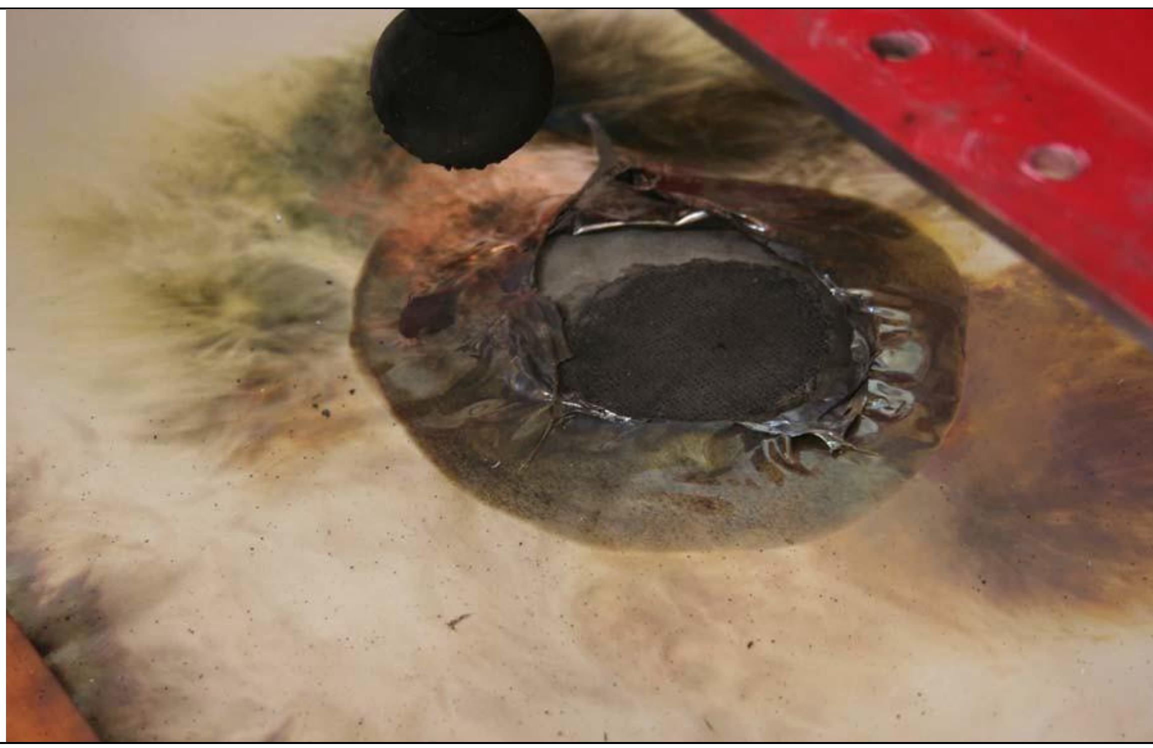
High Current Test – Panel LS-34 Setup



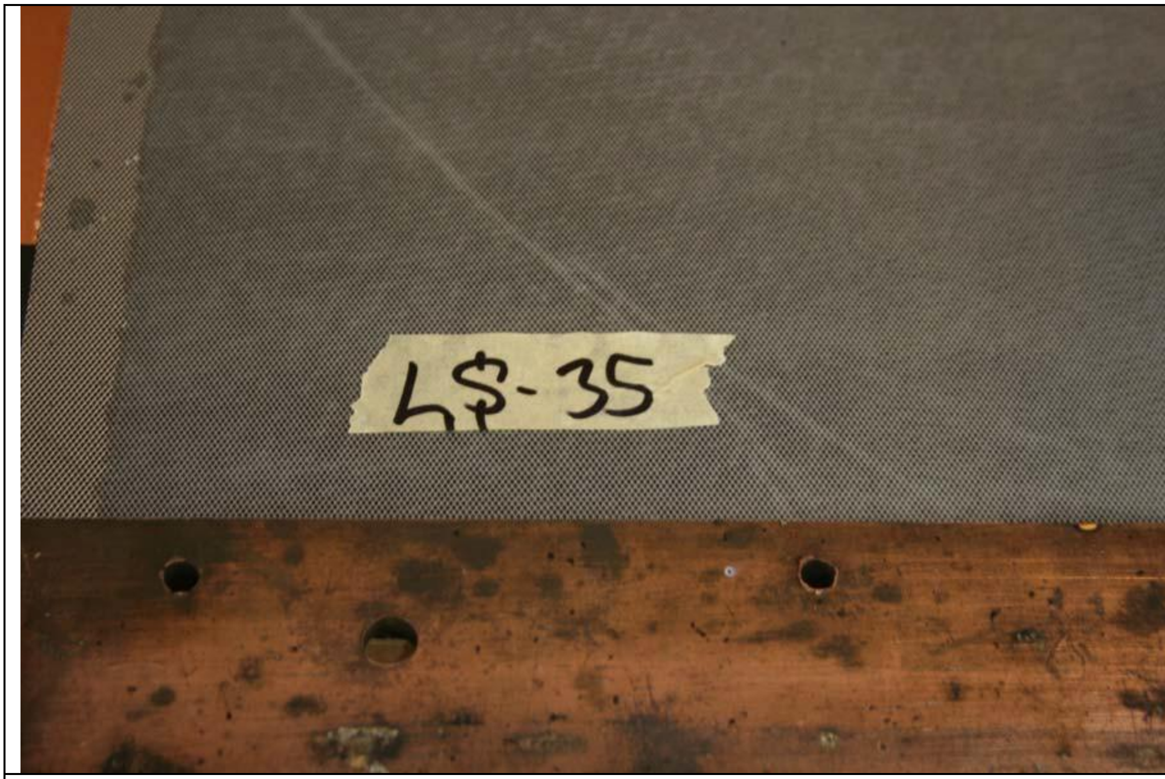
High Current Test – Panel LS-34 Pre-Strike



High Current Test – Panel LS-34 Components D, B, C*

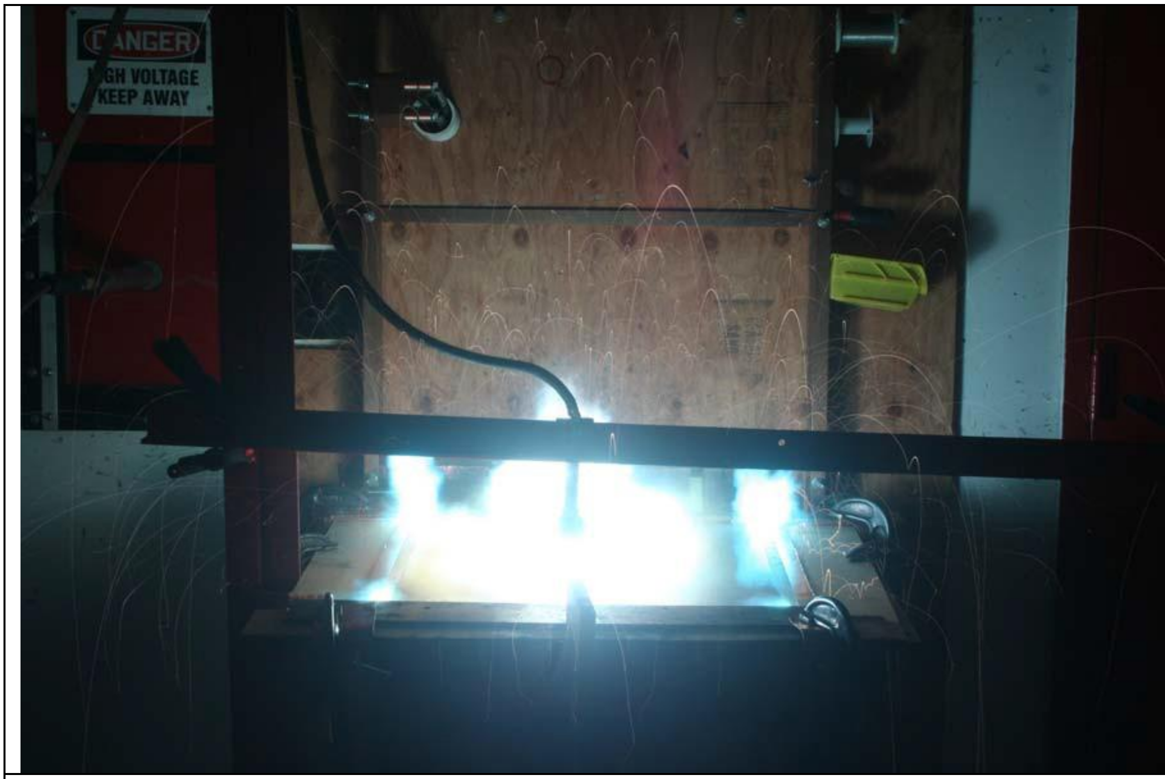


High Current Test – Panel LS-34 Post-Strike Damage



High Current Test – Panel LS-35 Setup

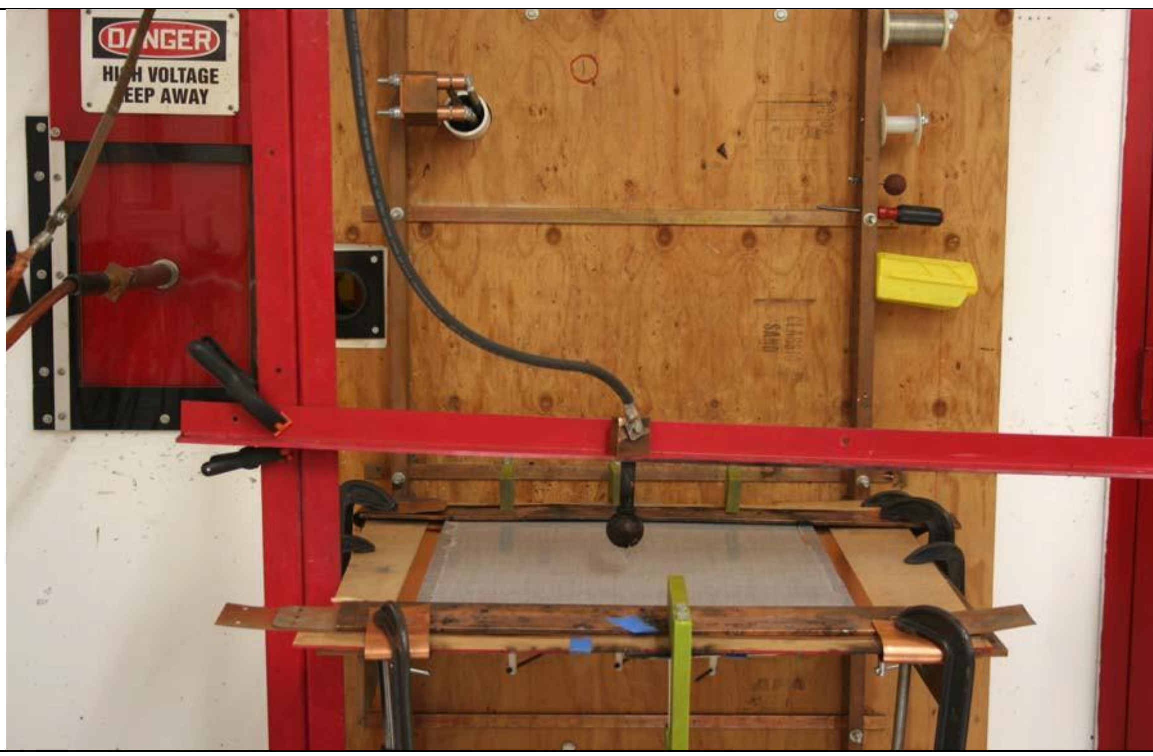
High Current Test – Panel LS-35 Pre-Strike



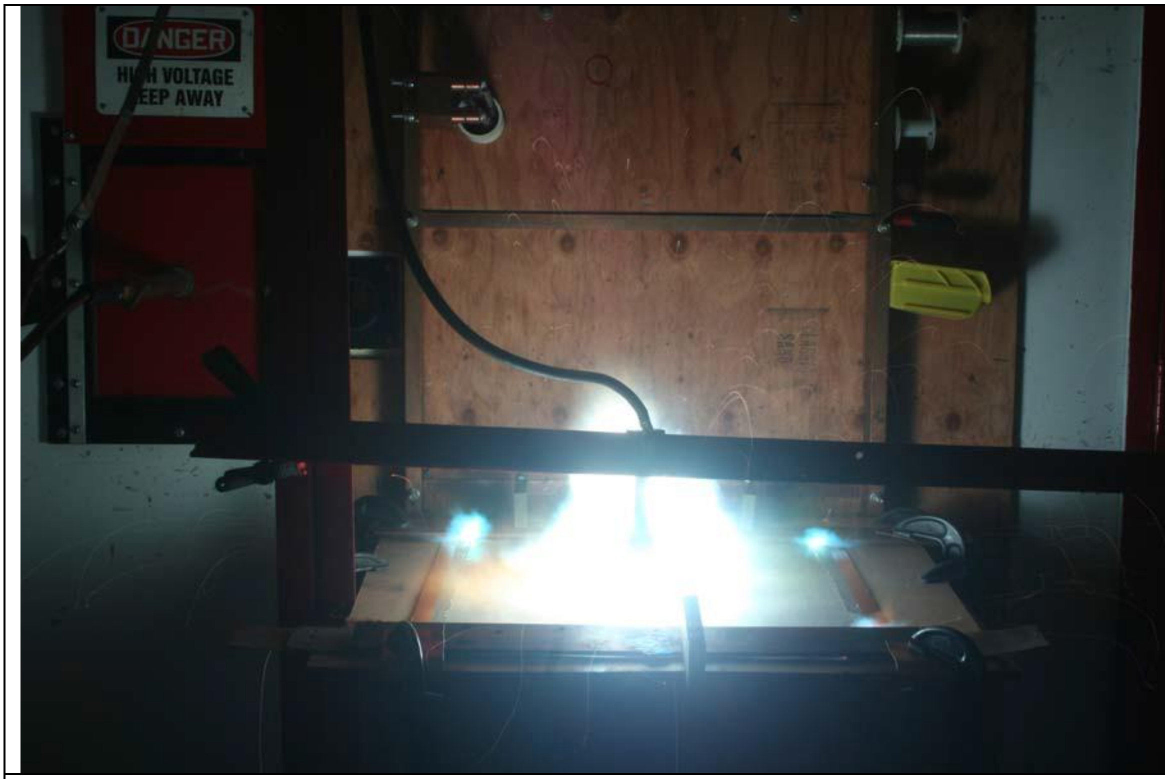
High Current Test – Panel LS-35 Components D, B, C*

High Current Test – Panel LS-35 Post-Strike Damage

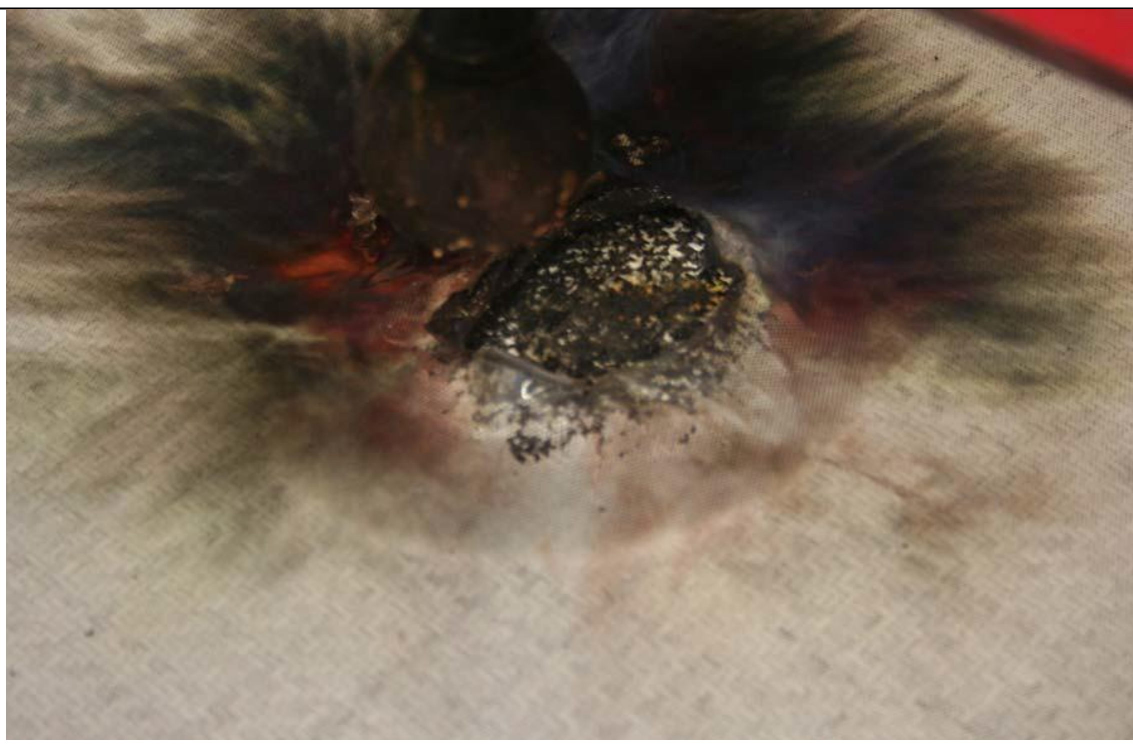
High Current Test – Panel LS-36 Setup



High Current Test – Panel LS-36 Pre-Strike

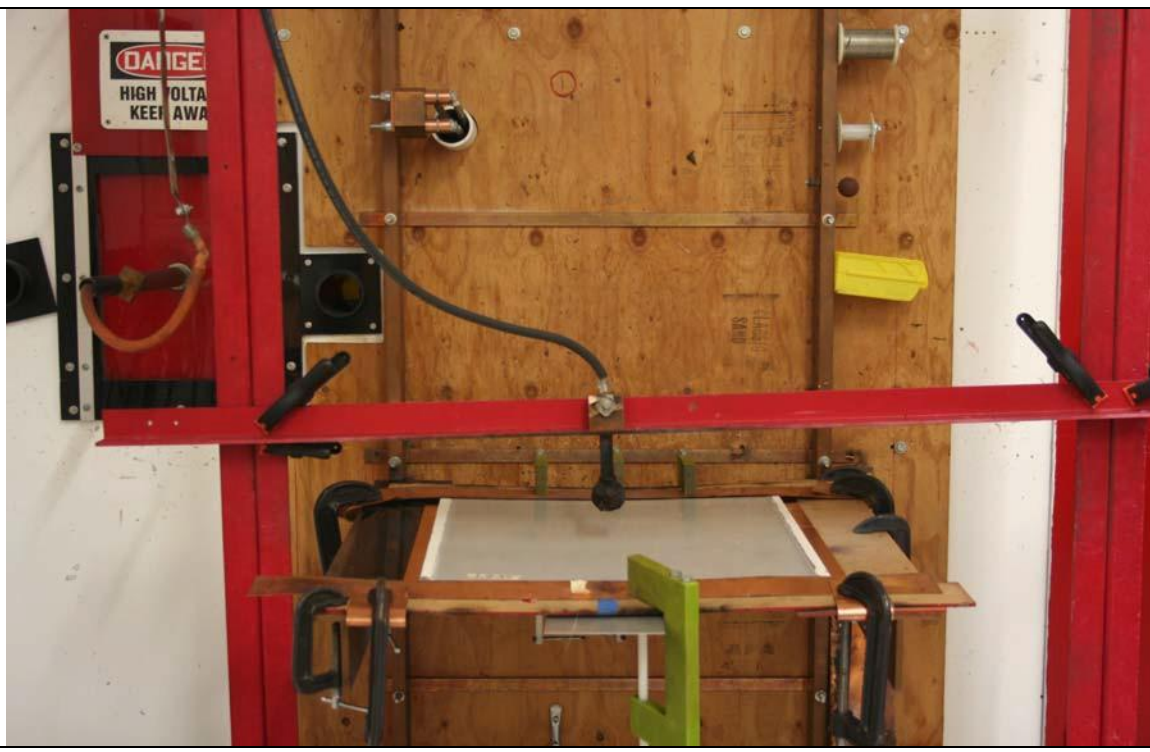


High Current Test – Panel LS-36 Components D, B, C*

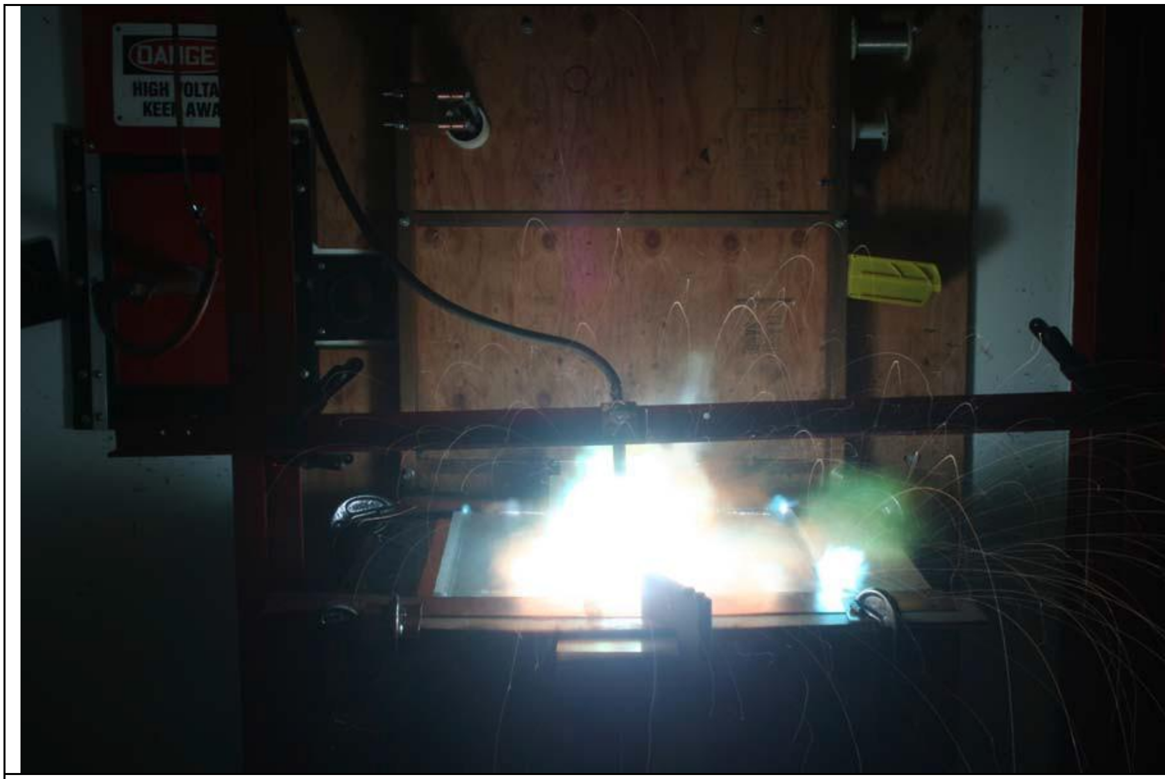


High Current Test – Panel LS-36 Post-Strike Damage

High Current Test – Panel LS-37 Setup



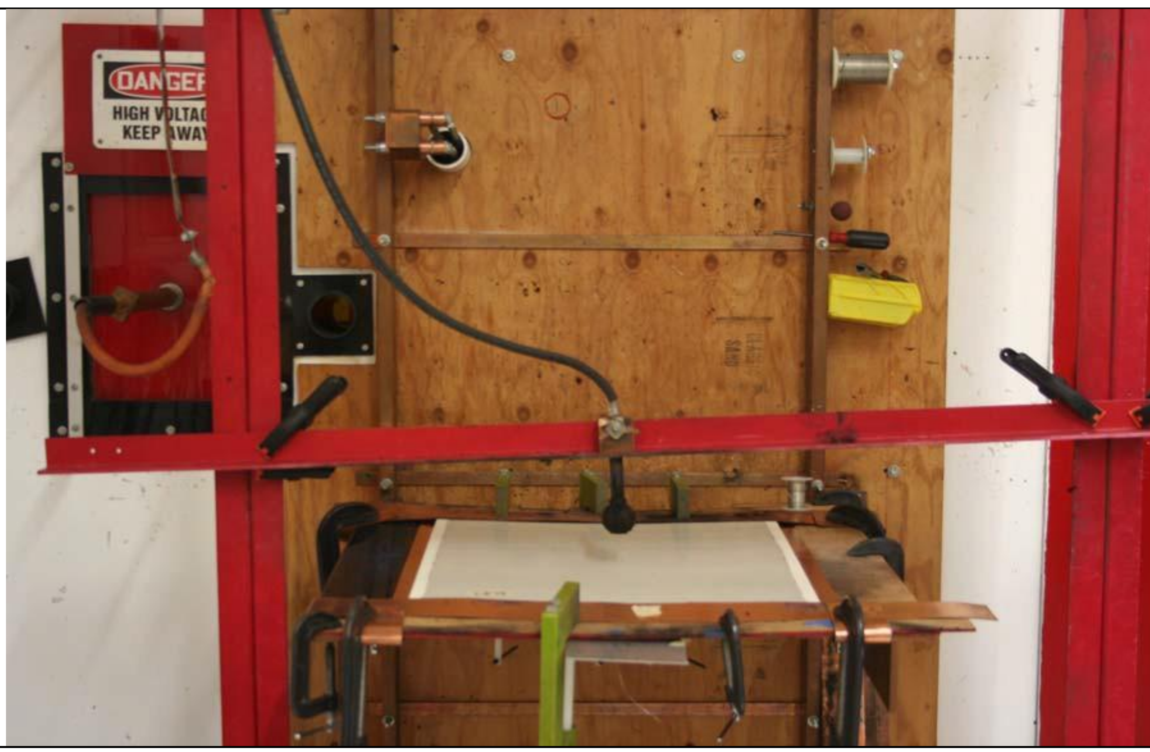
High Current Test – Panel LS-37 Pre-Strike



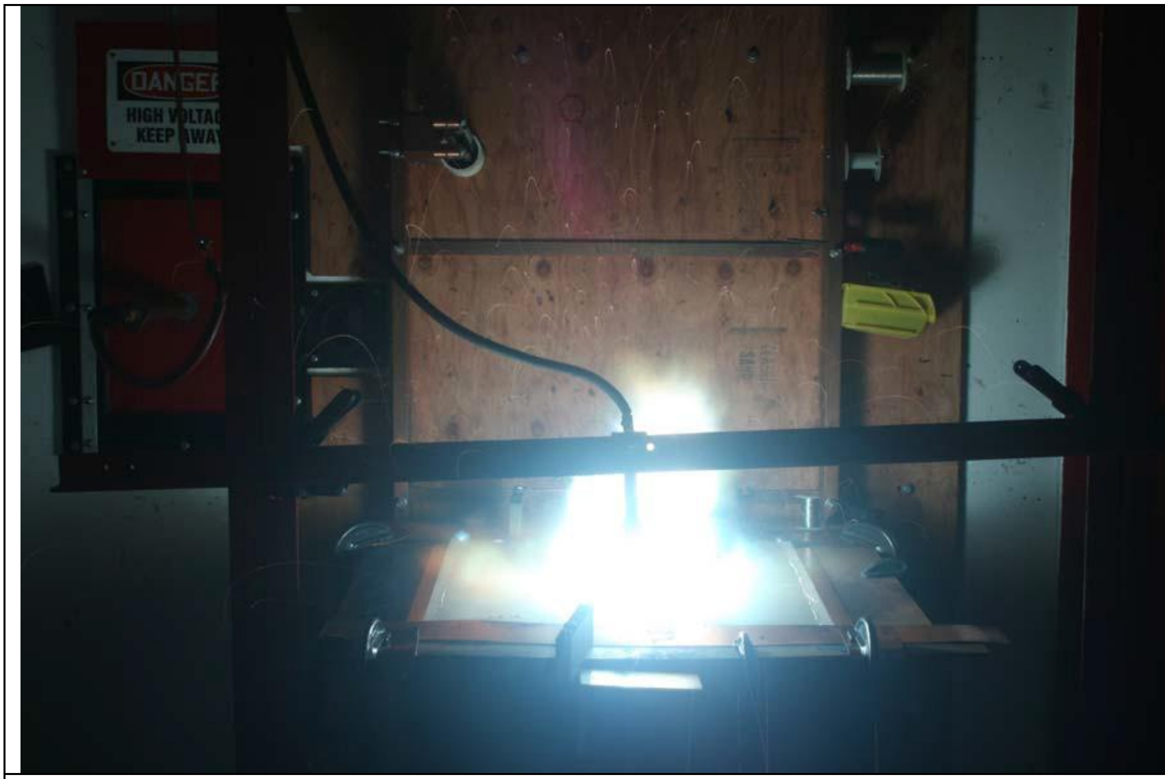
High Current Test – Panel LS-37 Components D, B, C*

High Current Test – Panel LS-37 Post-Strike Damage

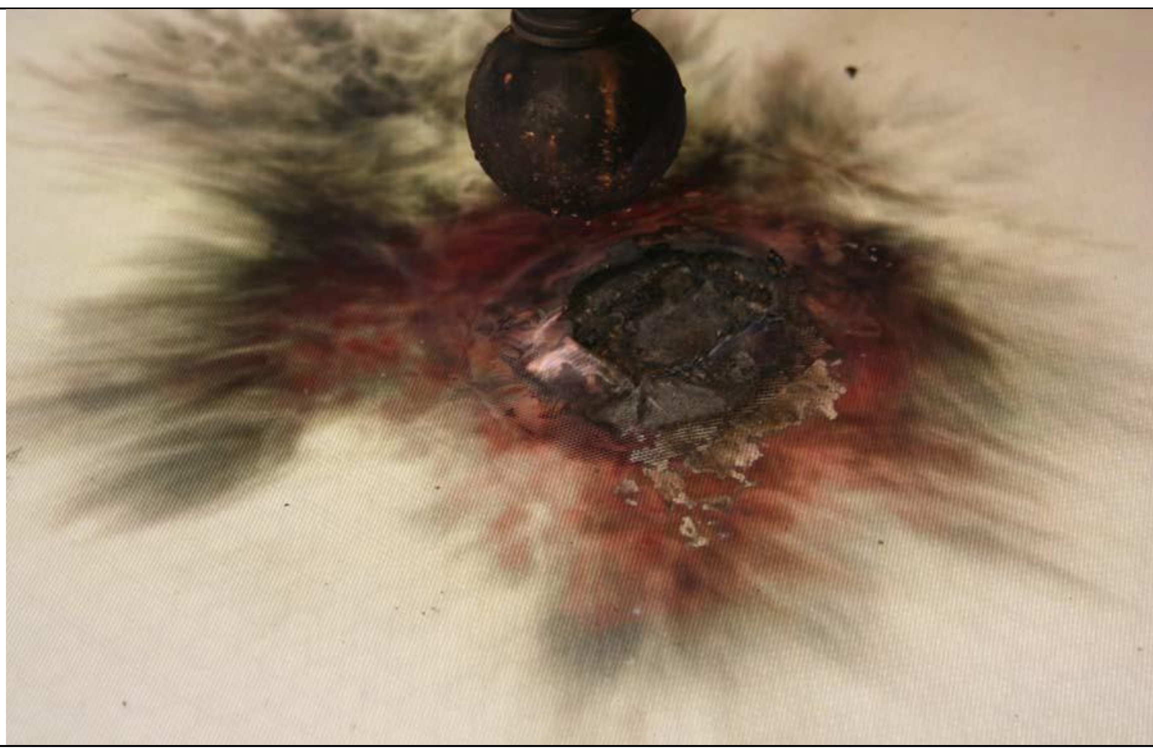
High Current Test – Panel LS-38 Setup



High Current Test – Panel LS-38 Pre-Strike

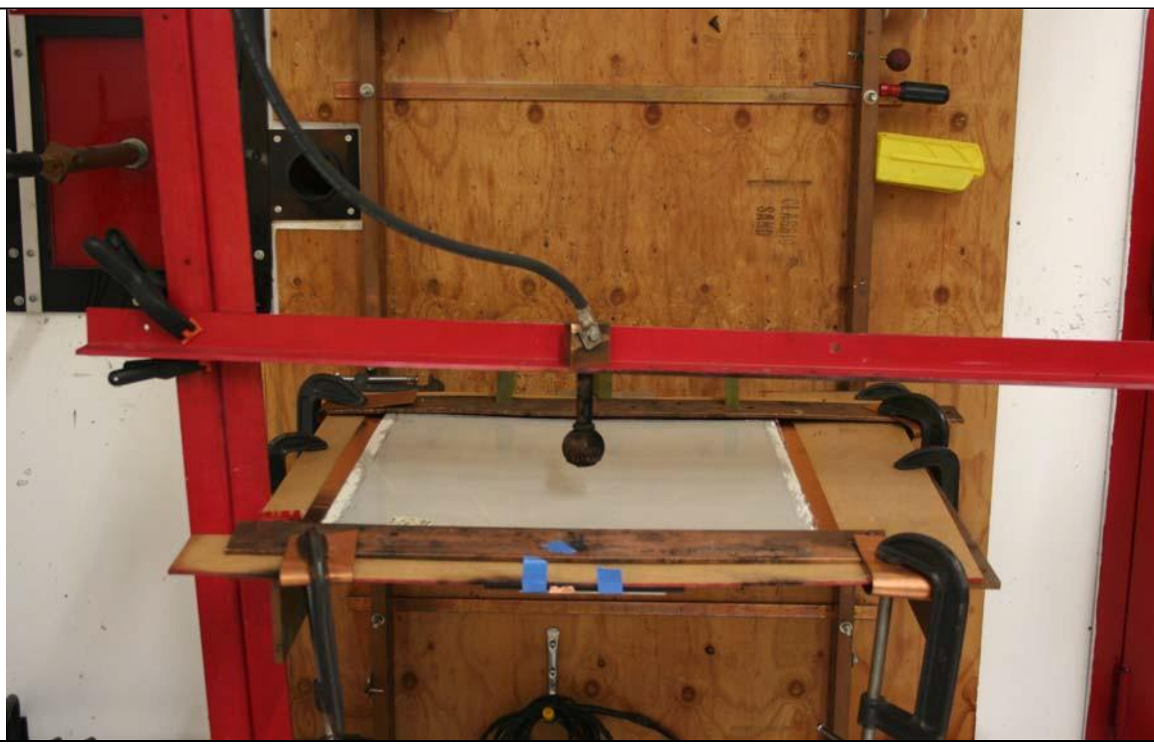


High Current Test – Panel LS-38 Components D, B, C*

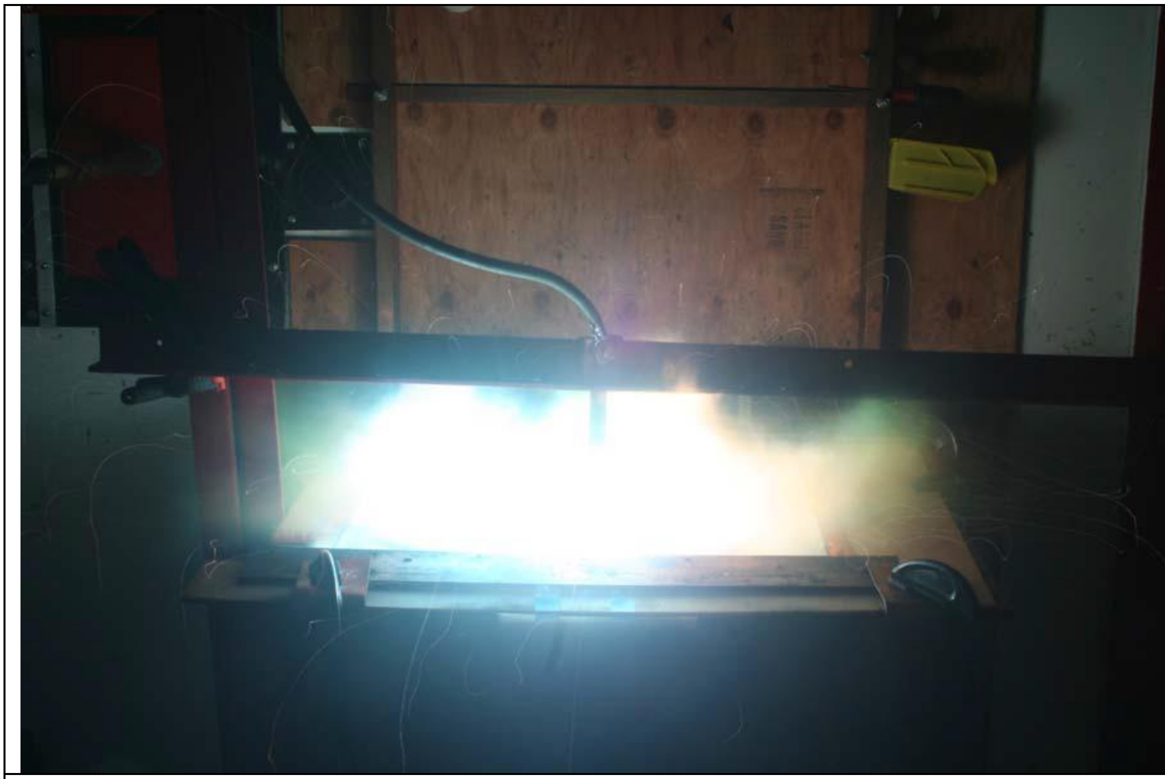


High Current Test – Panel LS-38 Post-Strike Damage

High Current Test – Panel LS-39 Setup



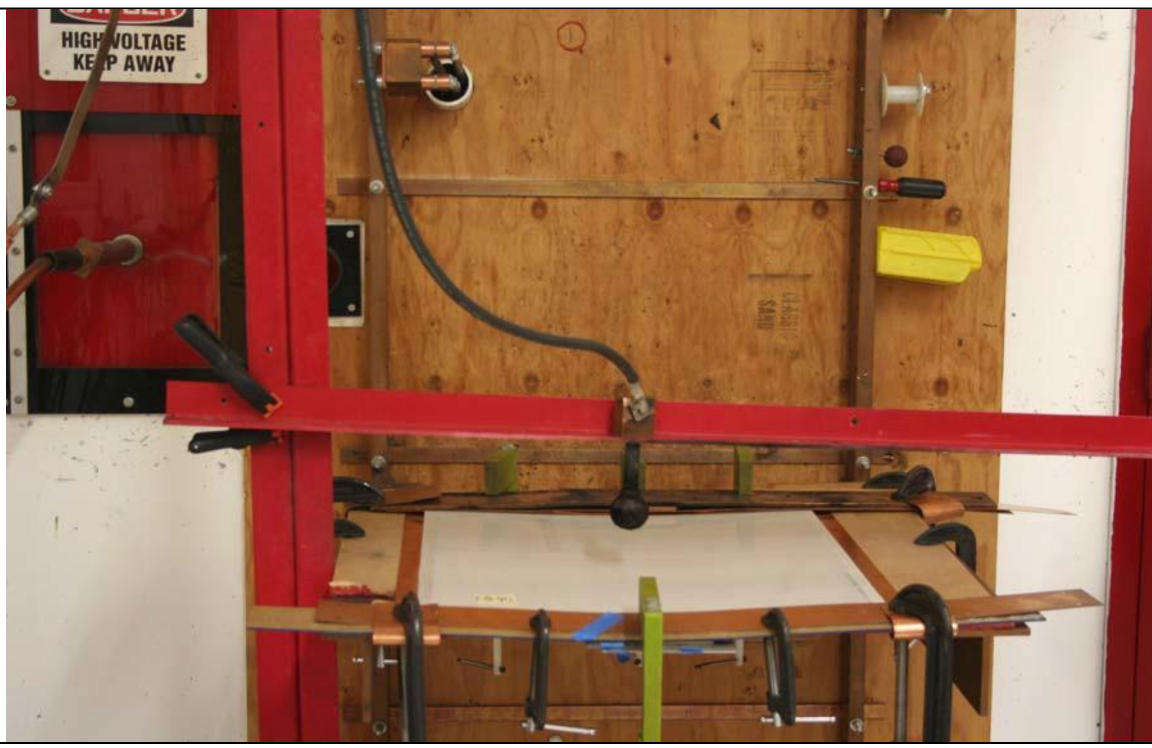
High Current Test – Panel LS-39 Pre-Strike



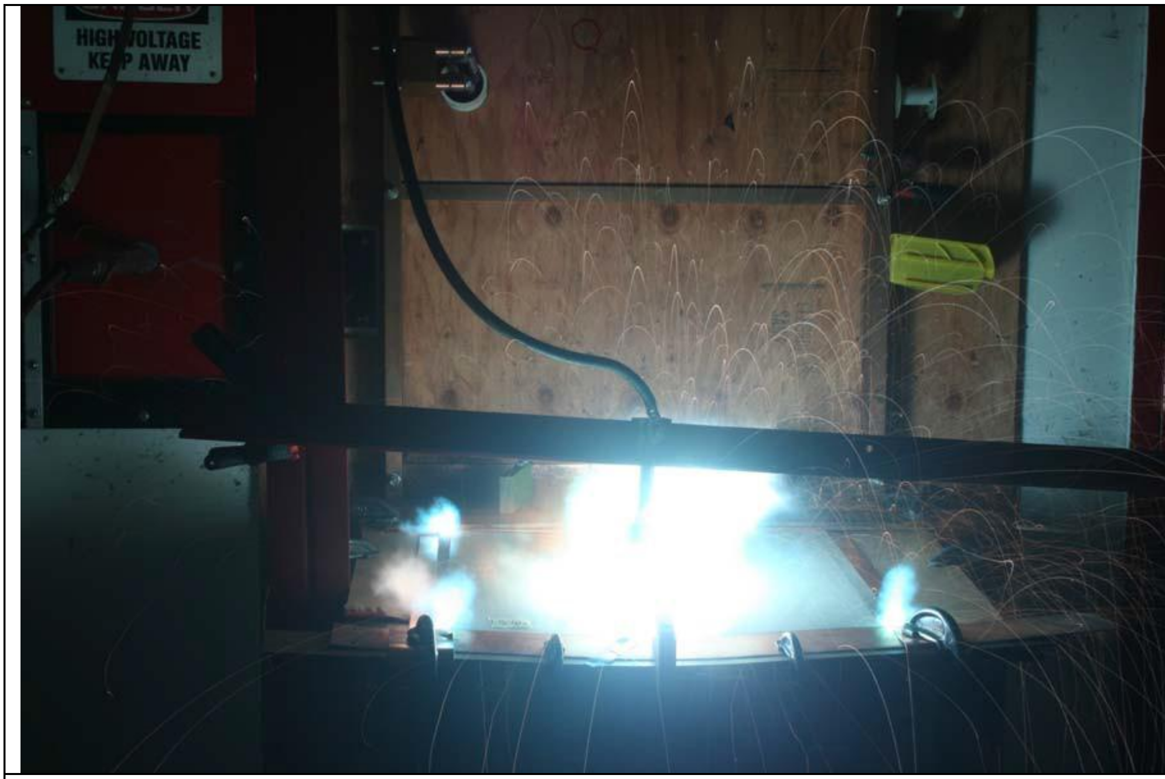
High Current Test – Panel LS-39 Components D, B, C*

High Current Test – Panel LS-39 Post-Strike Damage

High Current Test – Panel LS-40 Setup



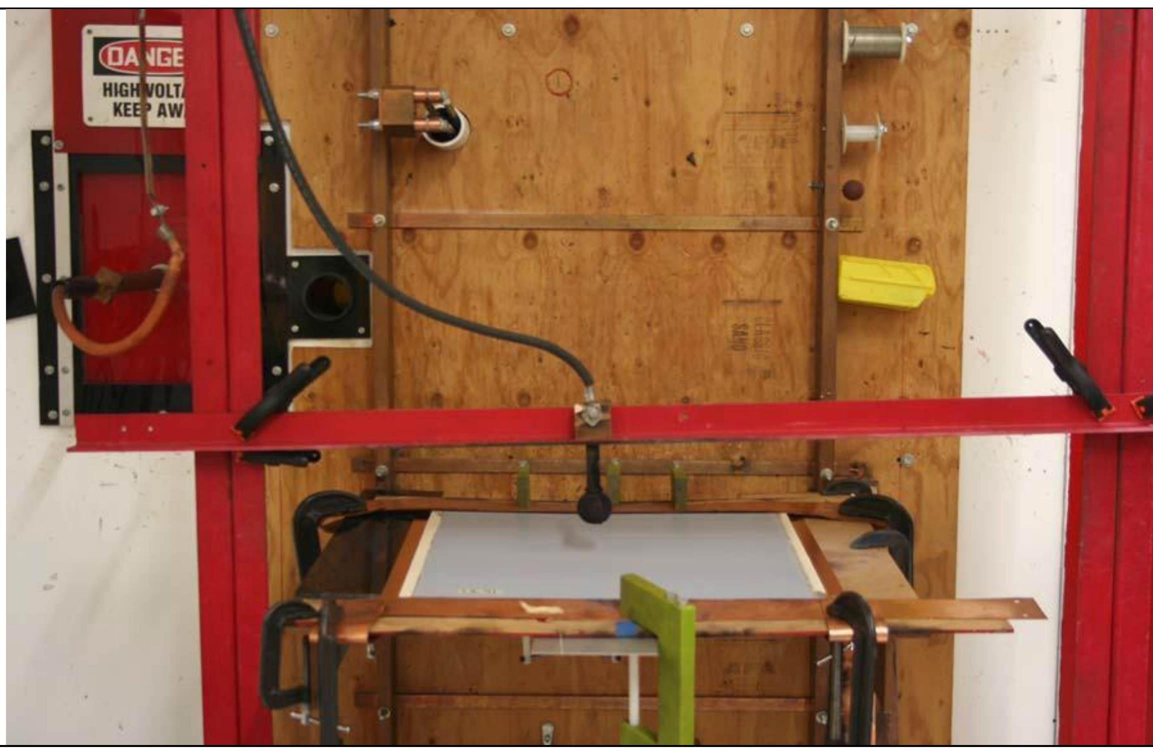
High Current Test – Panel LS-40 Pre-Strike

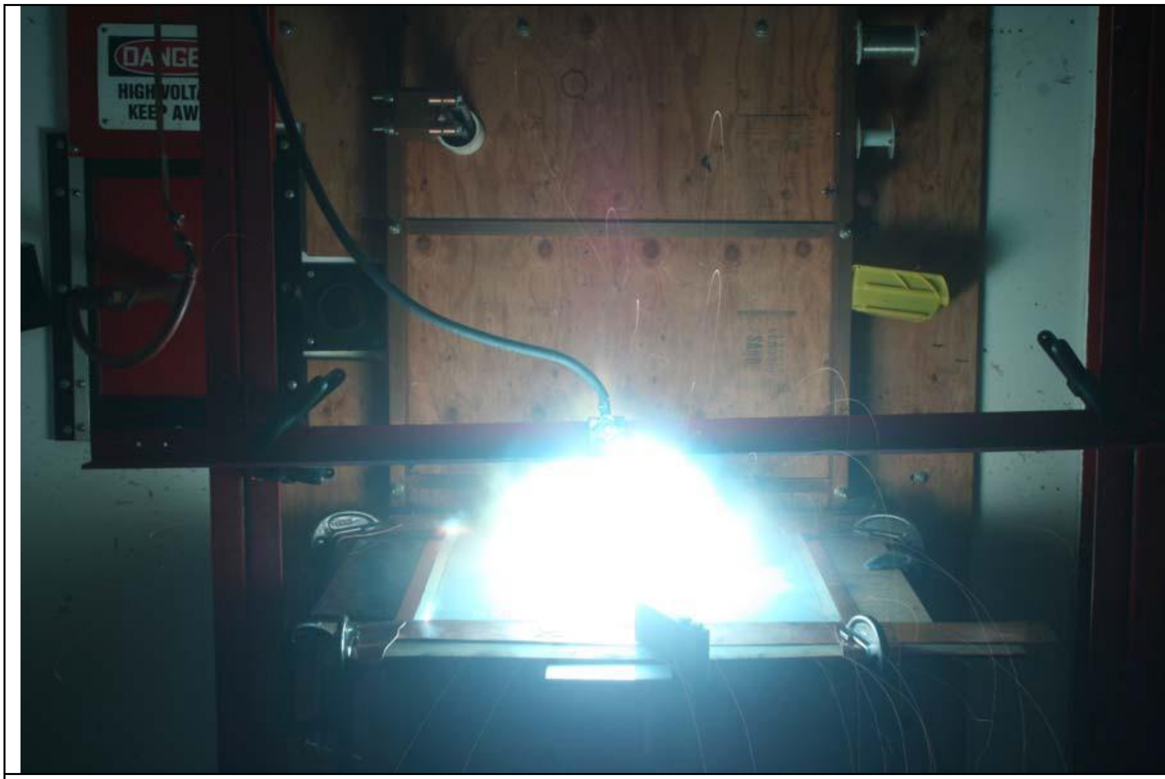


High Current Test – Panel LS-40 Components D, B, C*

High Current Test – Panel LS-40 Post-Strike Damage

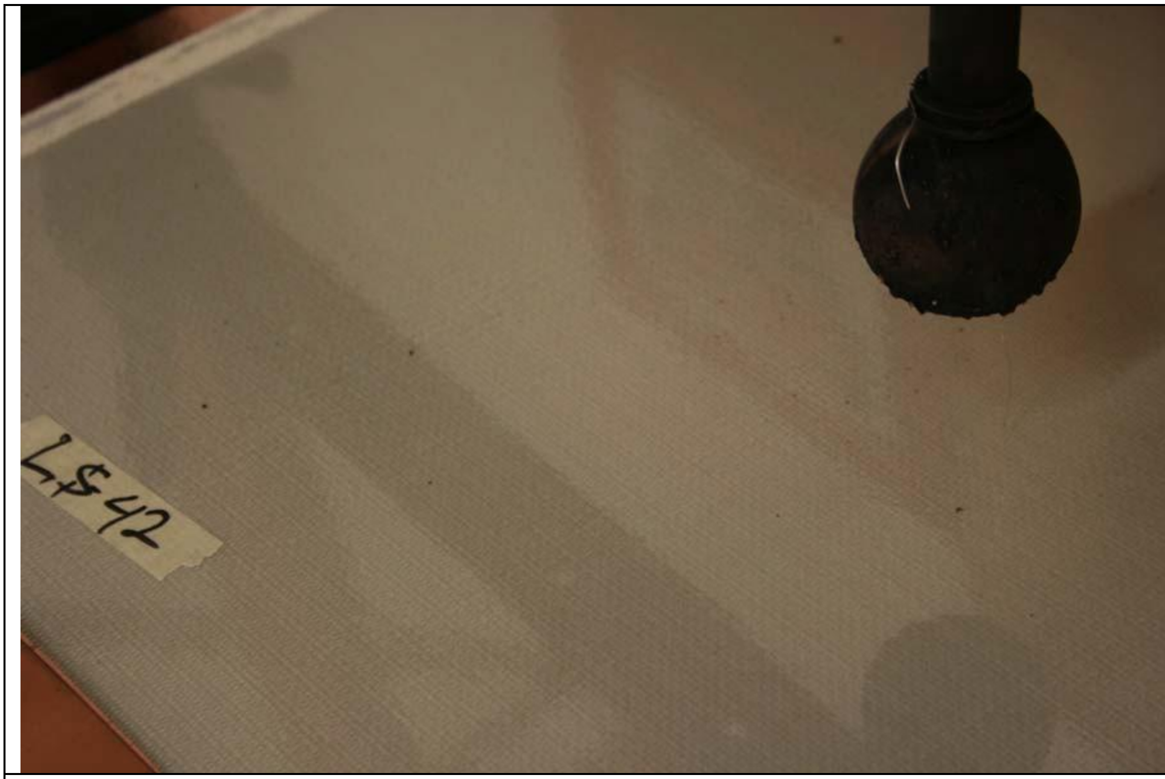
High Current Test – Panel LS-41 Setup


High Current Test – Panel LS-41 Pre-Strike

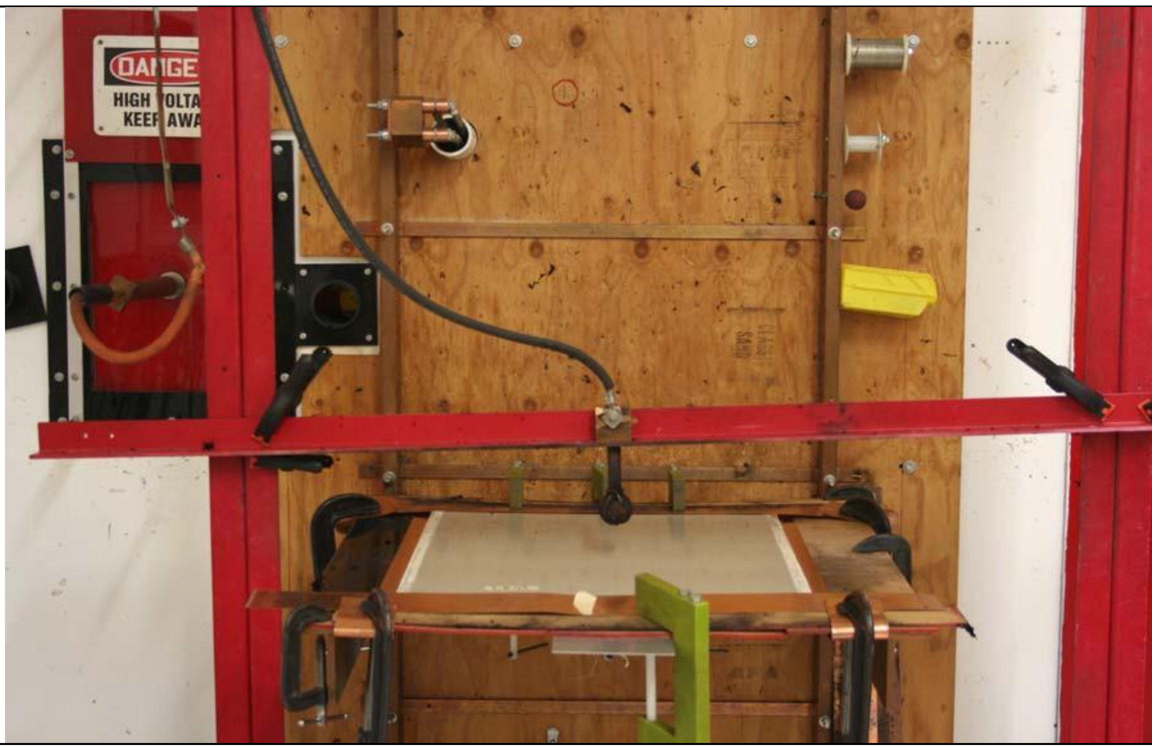


High Current Test – Panel LS-41 Components D, B, C*

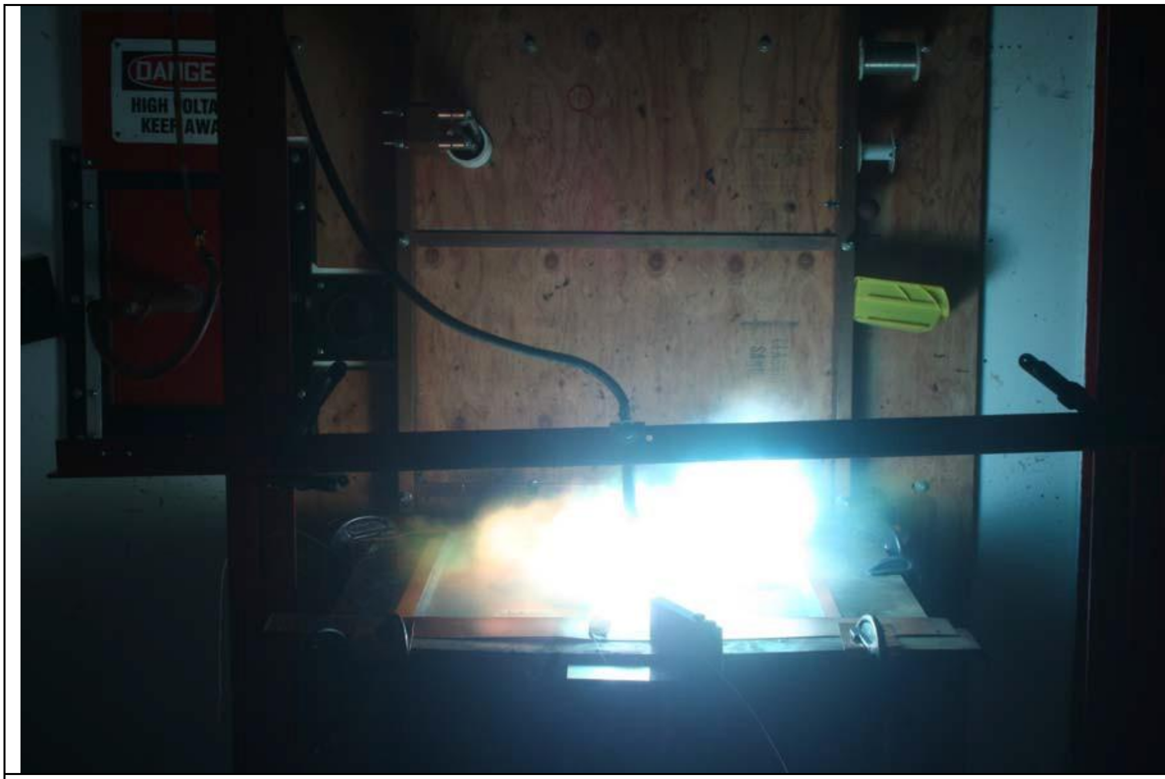
High Current Test – Panel LS-41 Post-Strike Damage



High Current Test – Panel LS-42 Setup



High Current Test – Panel LS-42 Pre-Strike

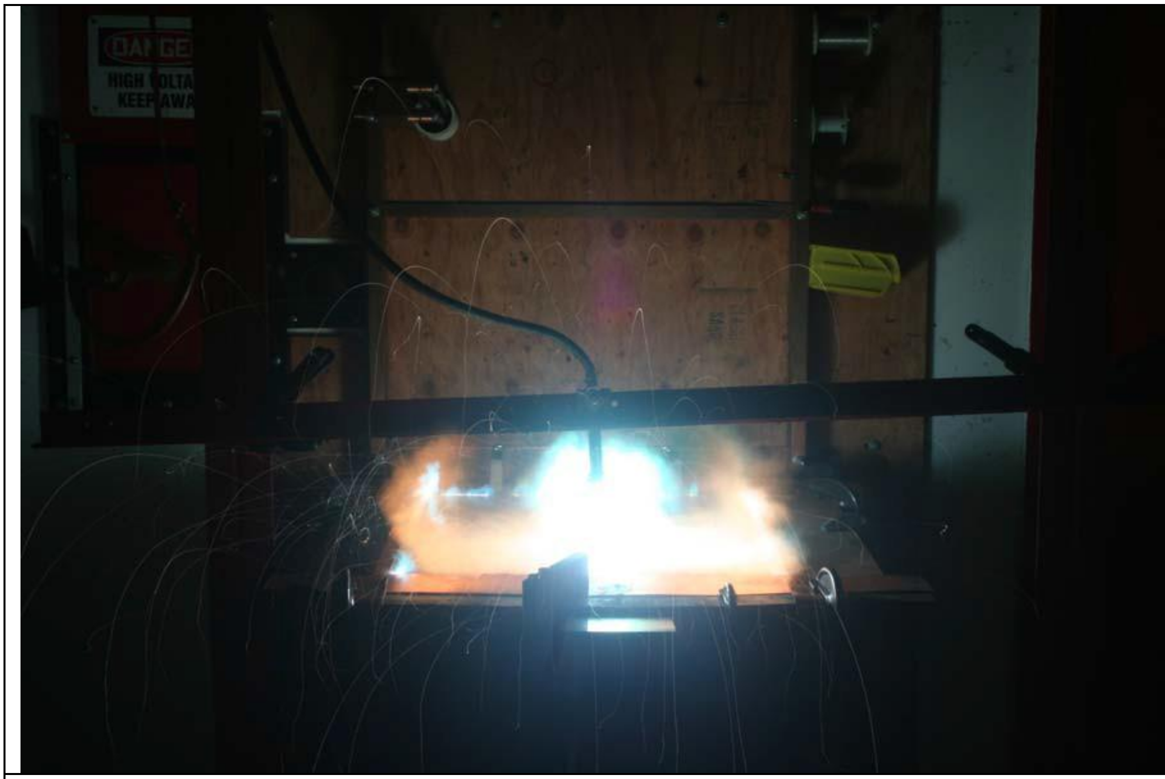


High Current Test – Panel LS-42 Components D, B, C*

High Current Test – Panel LS-42 Post-Strike Damage

High Current Test – Panel LS-43 Setup

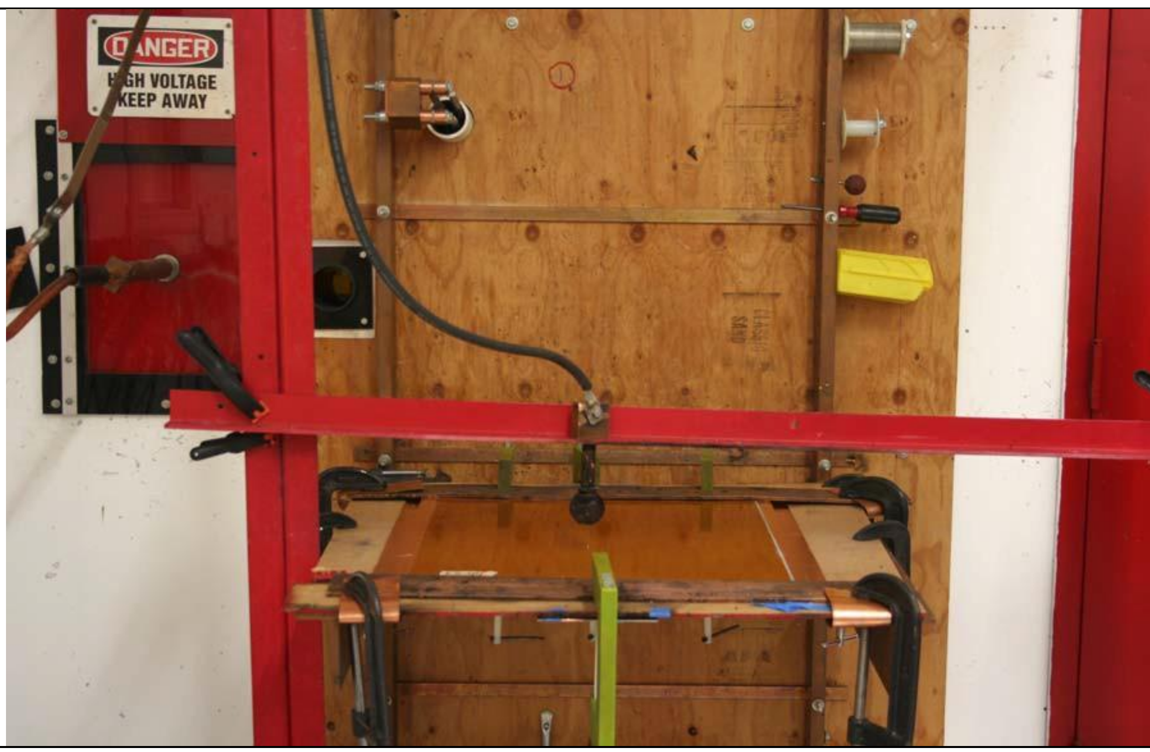
High Current Test – Panel LS-43 Pre-Strike



High Current Test – Panel LS-43 Components D, B, C*

High Current Test – Panel LS-43 Post-Strike Damage

High Current Test – Panel LS-44 Setup



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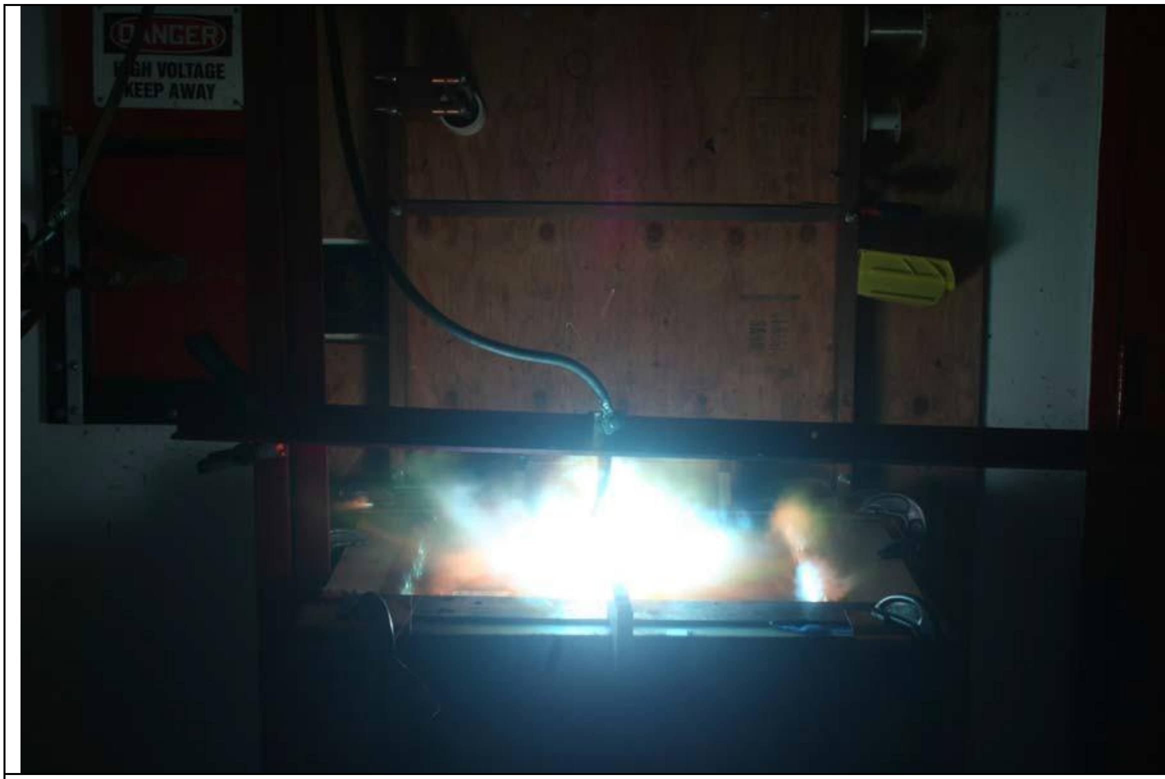
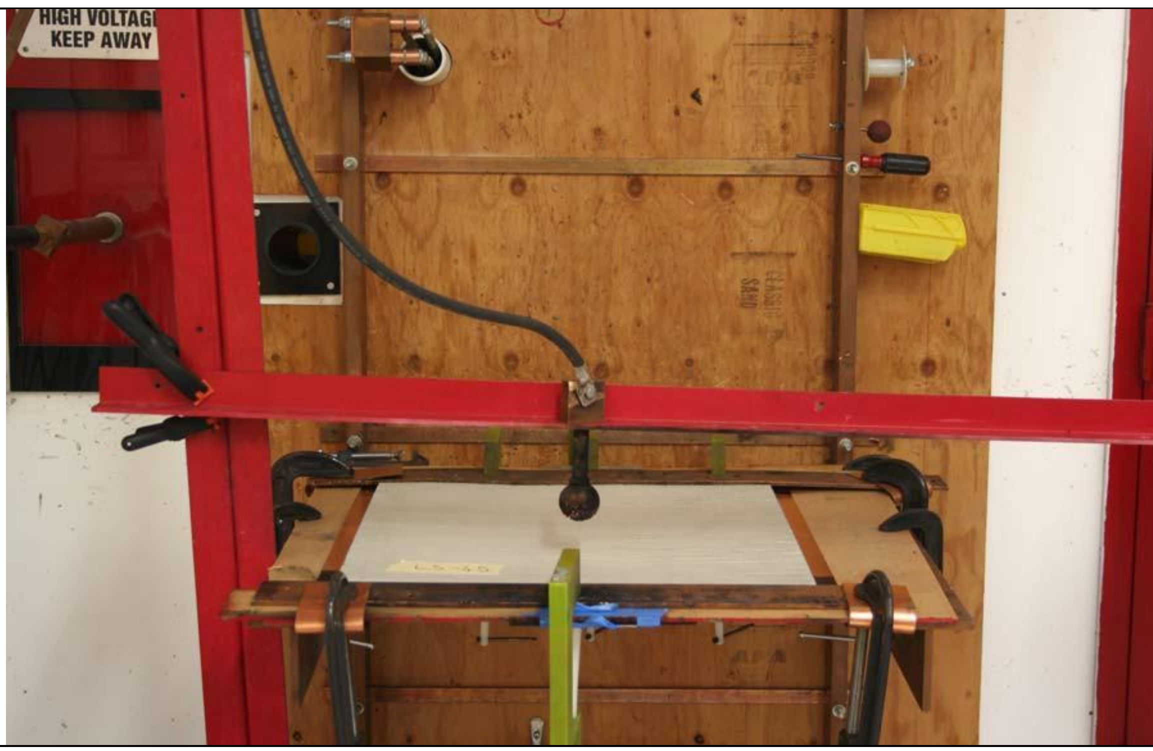


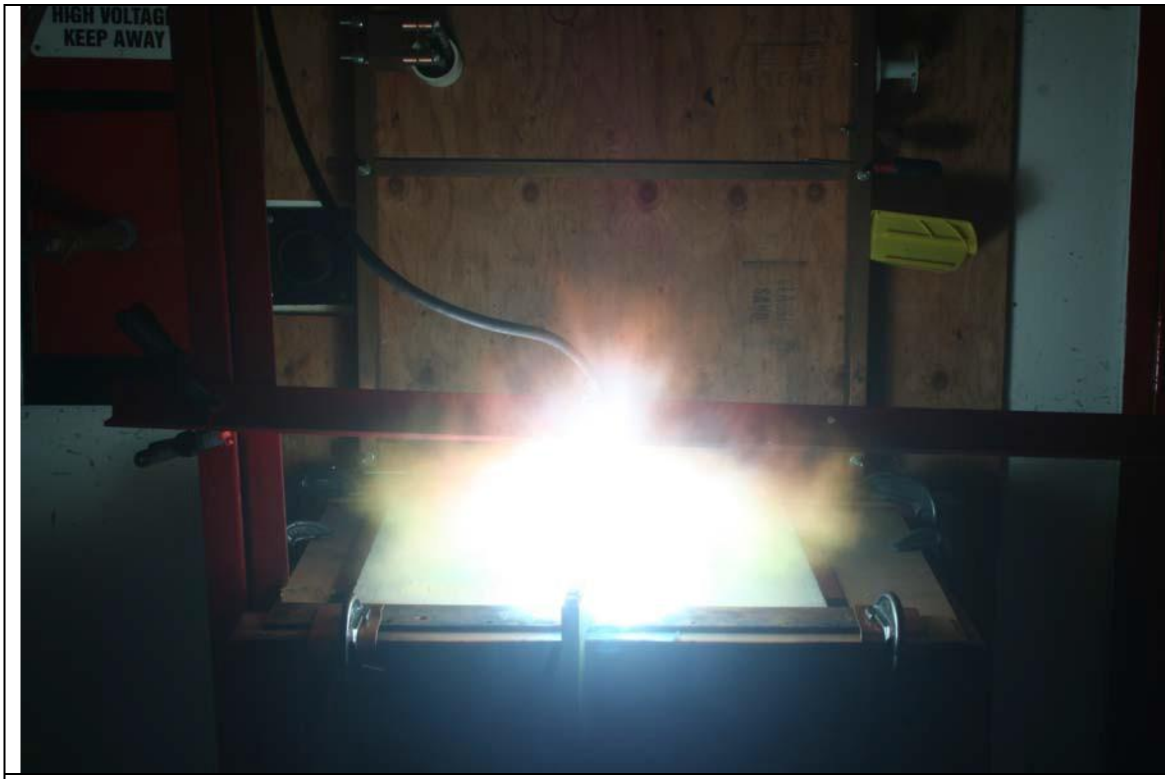
High Current Test – Panel LS-44 Components D, B, C*

High Current Test – Panel LS-44 Post-Strike Damage

High Current Test – Panel LS-45 Setup

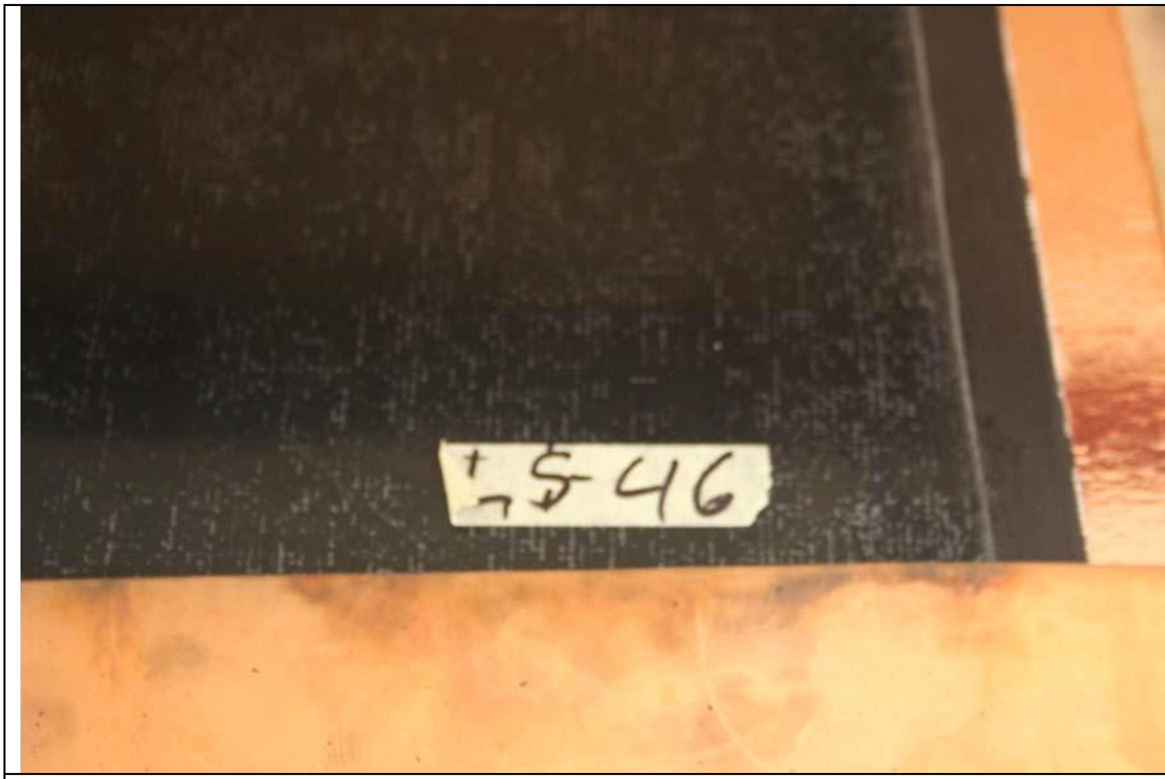


High Current Test – Panel LS-45 Pre-Strike

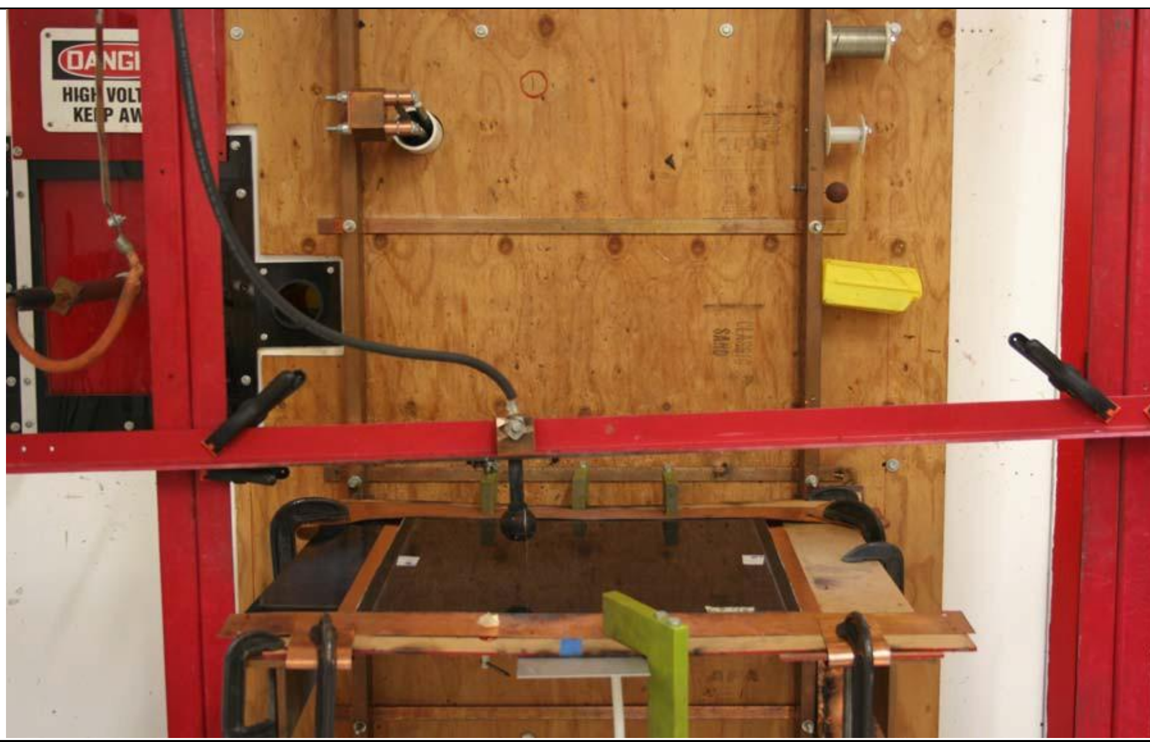


High Current Test – Panel LS-45 Components D, B, C*

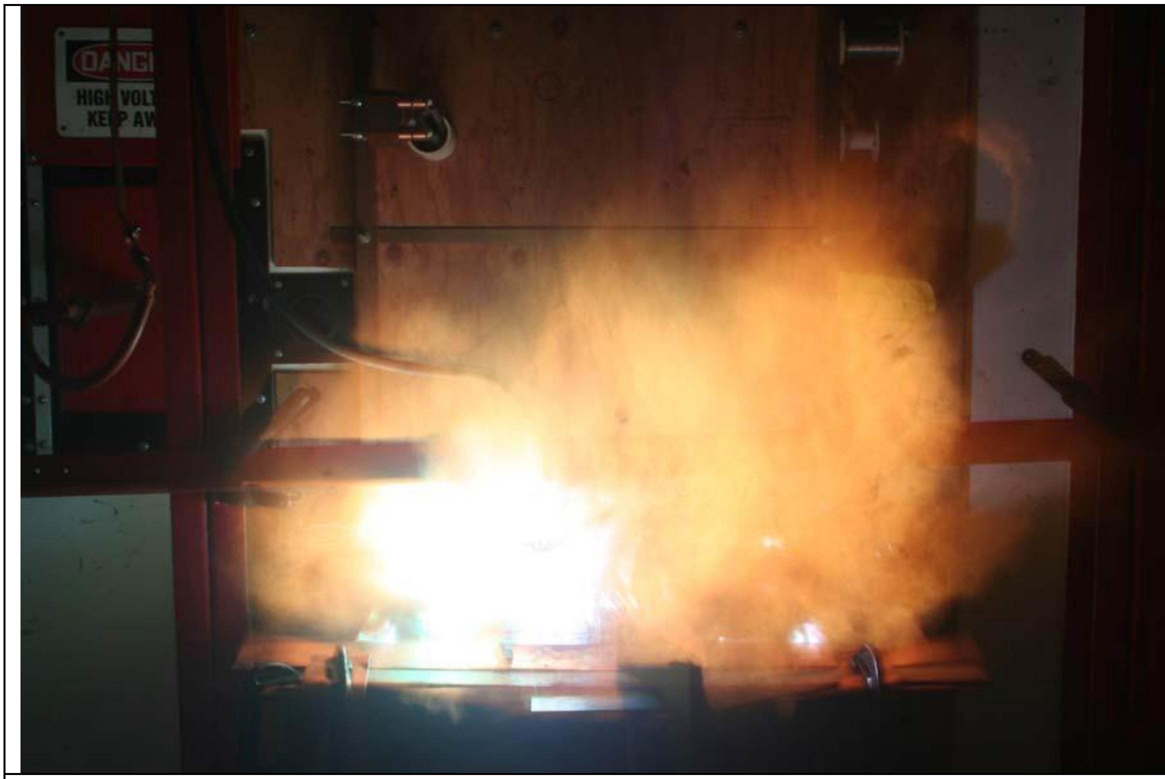
High Current Test – Panel LS-45 Post-Strike Damage



High Current Test – Panel LS-46 Side 1Setup

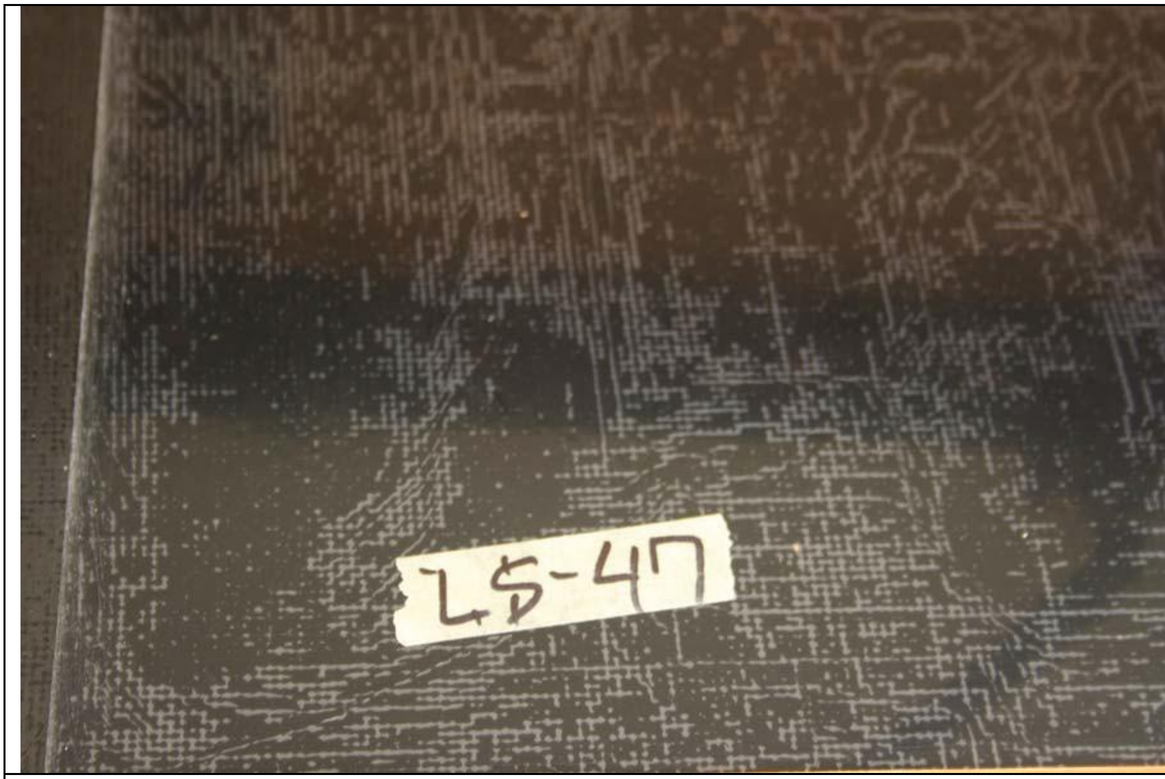


High Current Test – Panel LS-46 Side 1 Pre-Strike

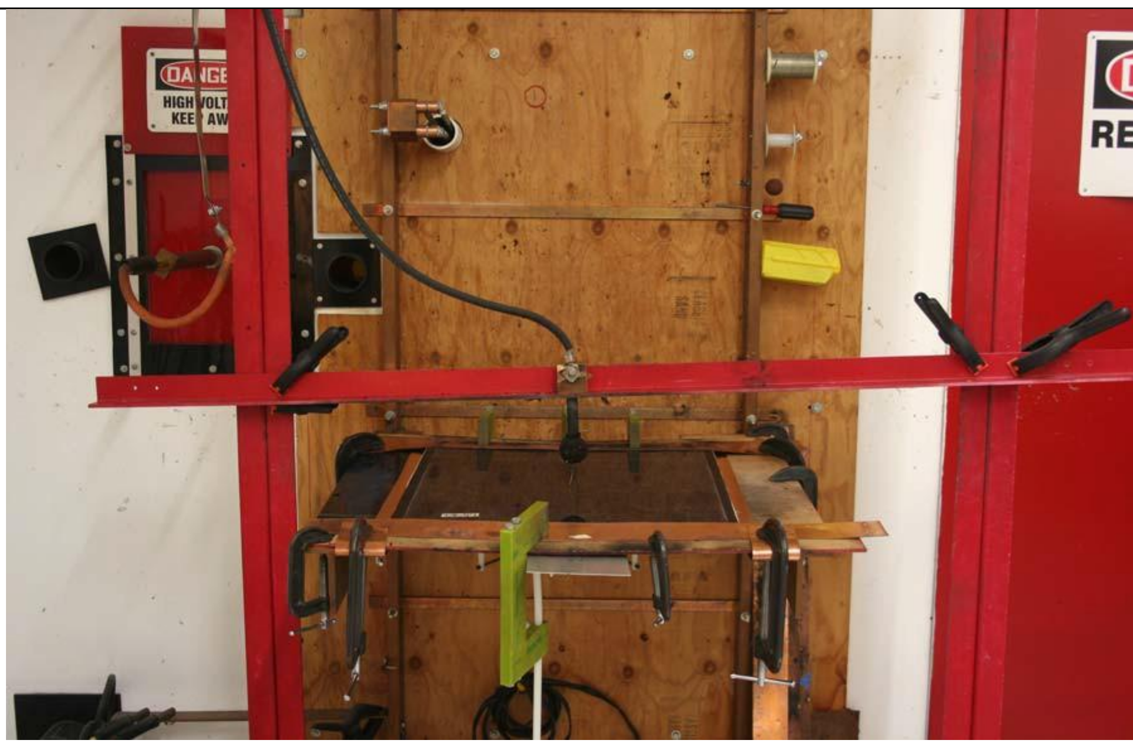


High Current Test – Panel LS-46 Side 1 Components D, B, C*

High Current Test – Panel LS-46 Post-Strike Damage



High Current Test – Panel LS-47 Setup



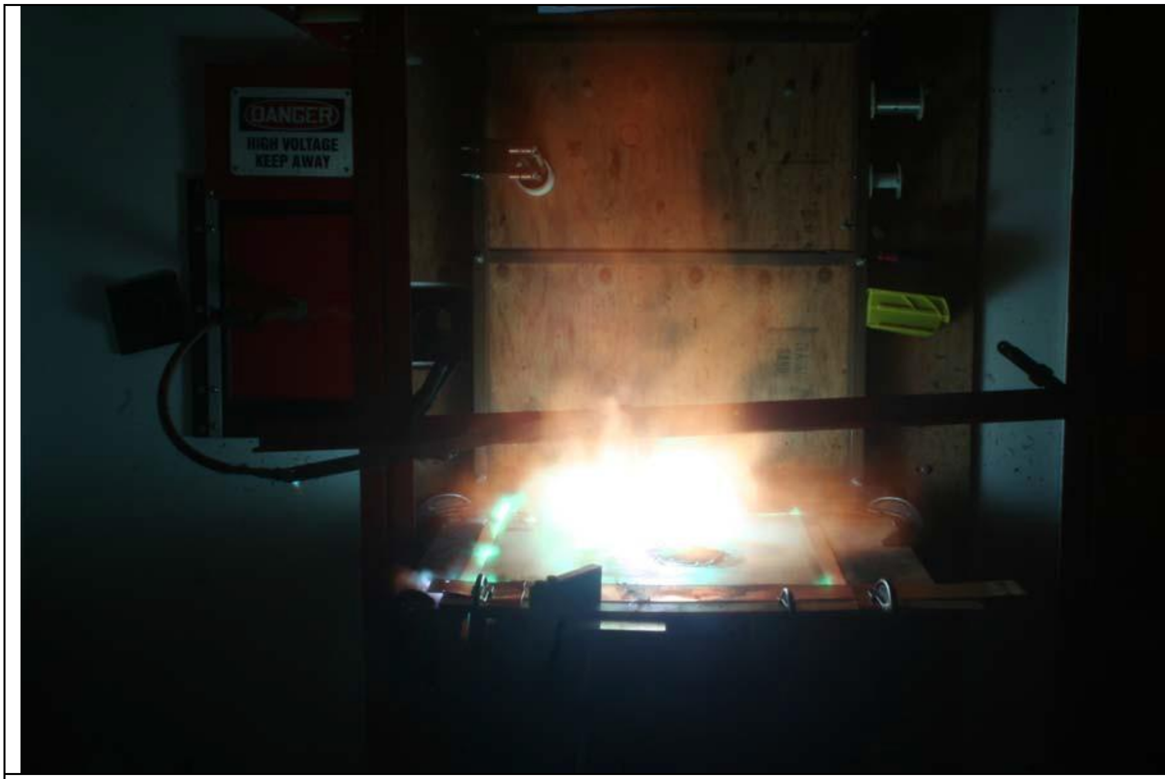
High Current Test – Panel LS-47 Pre-Strike

High Current Test – Panel LS-47 Components D, B, C*

High Current Test – Panel LS-47 Post-Strike Damage

High Current Test – Panel LS-34 Setup

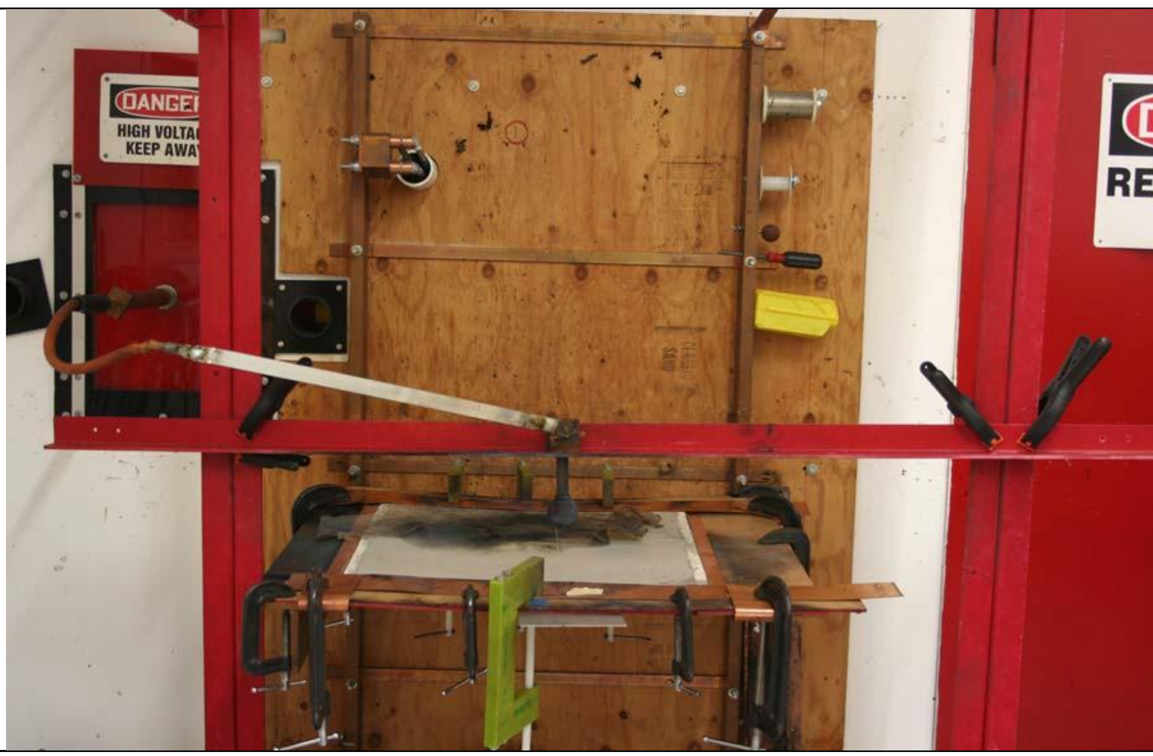
High Current Test – Panel LS-34 Pre-Strike



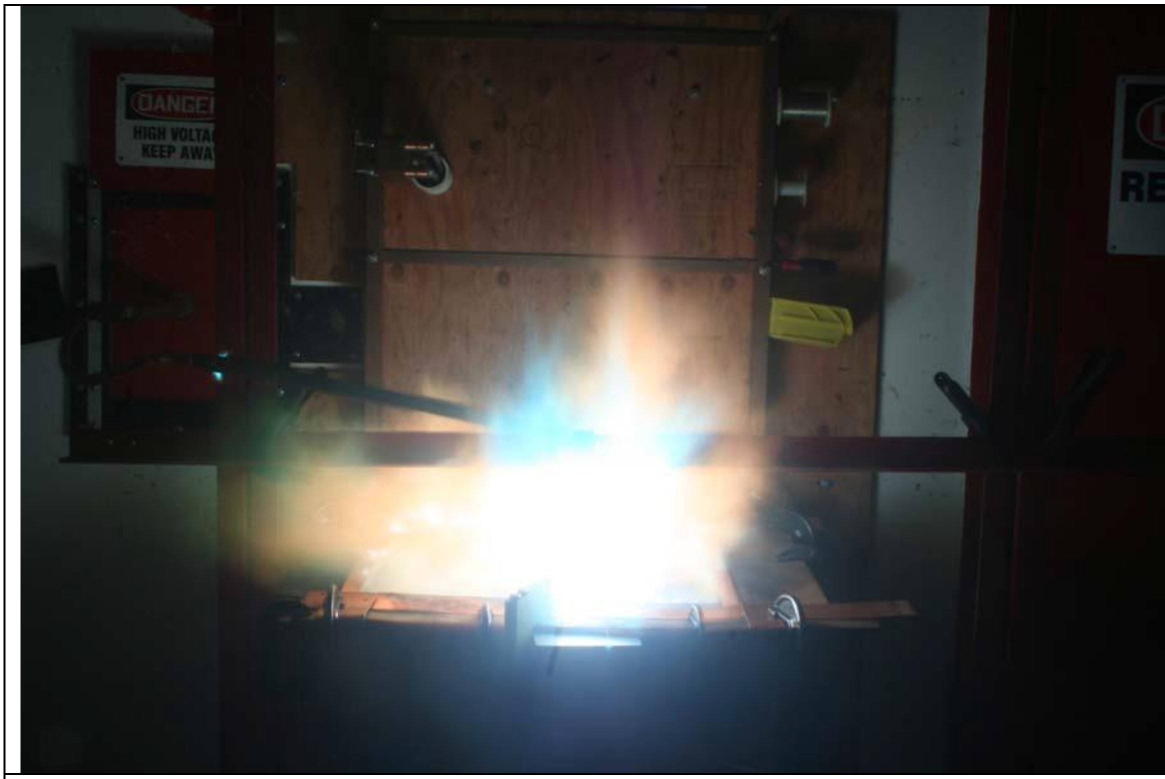
High Current Test – Panel LS-34 Components A, B, C*

High Current Test – Panel LS-34 Post-Strike Damage

High Current Test – Panel LS-39 Setup

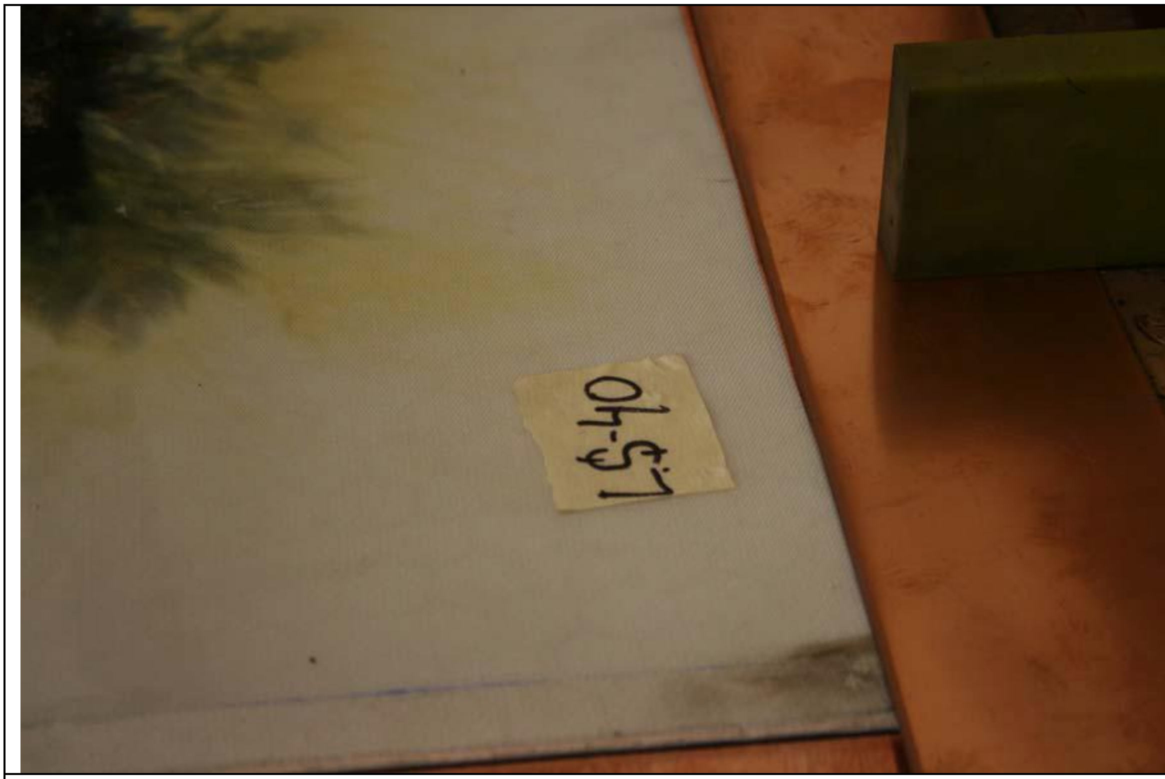


High Current Test – Panel LS-39 Pre-Strike



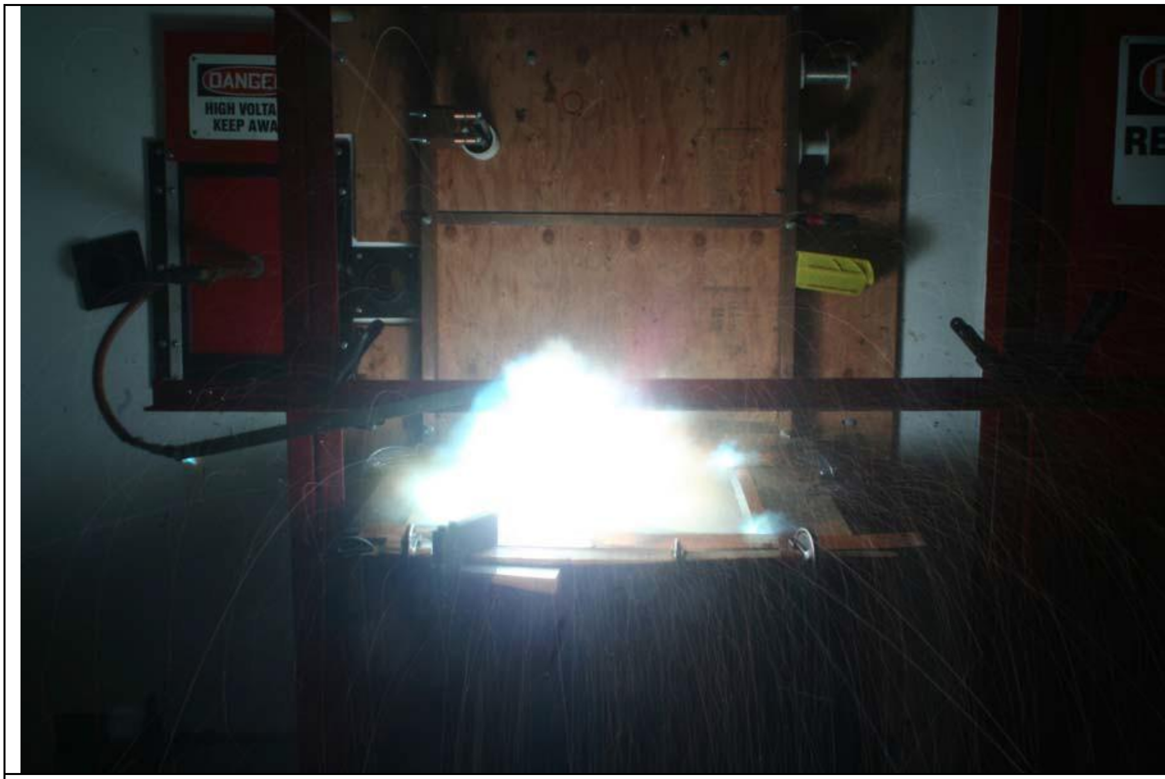
High Current Test – Panel LS-39 Components A, B, C*

High Current Test – Panel LS-39 Post-Strike Damage

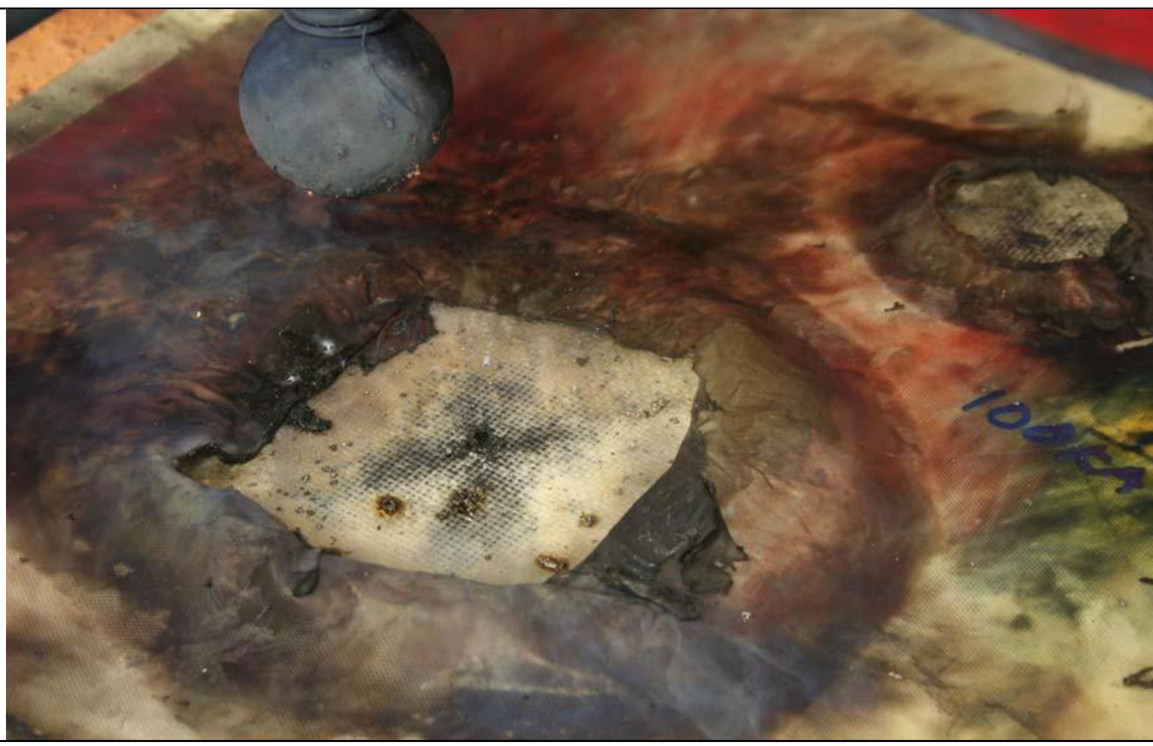


High Current Test – Panel LS-40 Setup

High Current Test – Panel LS-40 Pre-Strike



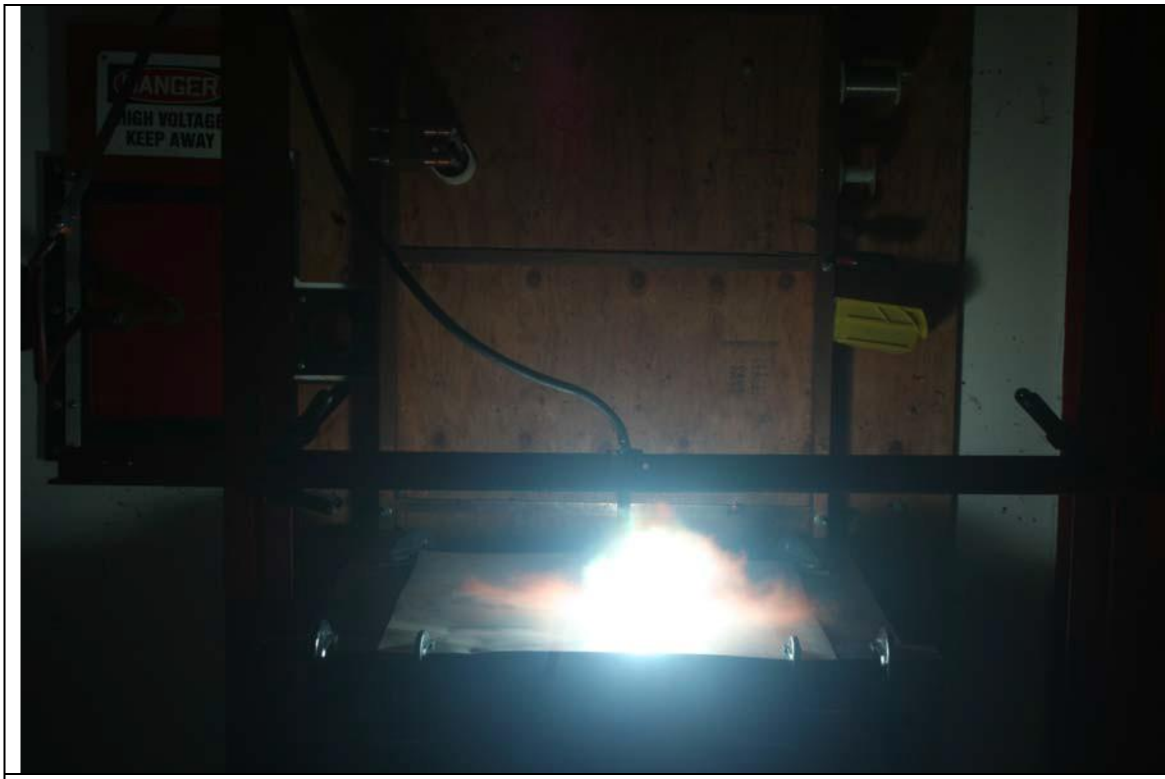
High Current Test – Panel LS-40 Components A, B, C*



High Current Test – Panel LS-40 Post-Strike Damage

High Current Test – Calibration Panel Setup

High Current Test – Calibration Panel Pre-Strike



High Current Test – Calibration Panel Components D, B, C*

High Current Test – Calibration Panel Post-Strike Damage

END OF REPORT

SIZE	CAGE CODE	DRAWING NO.
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SCALE: NONE	**REV LTR -**	**FINAL SHEET**

Appendix I
First-Generation Direct Effects Pictures (Cessna)

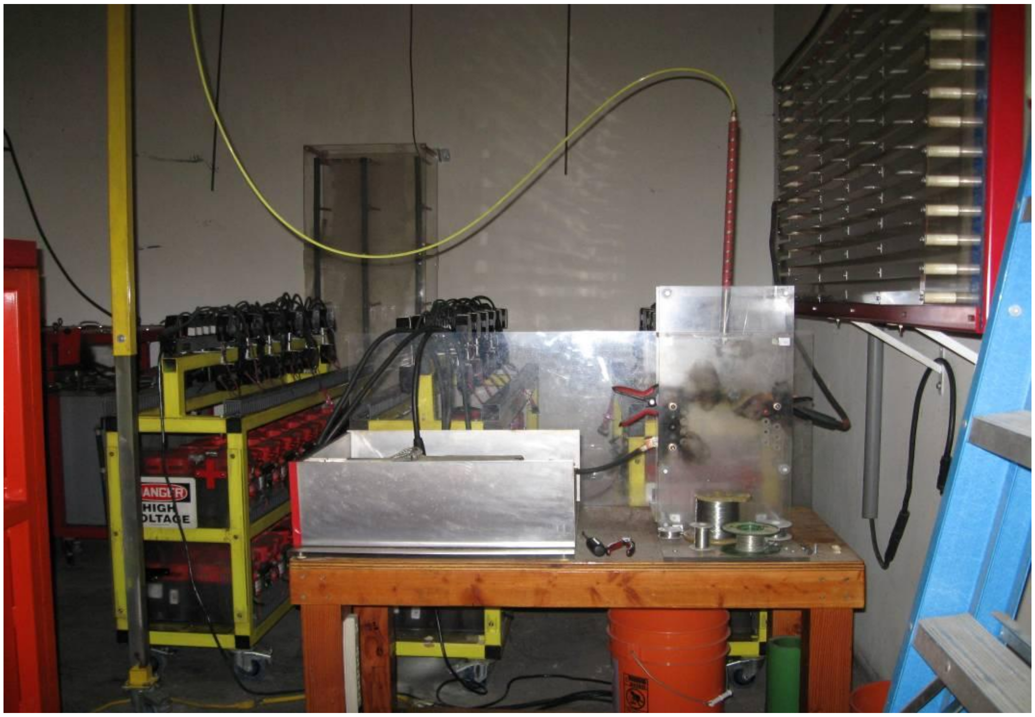


Figure I-1: Capacitor bank at DNB for DEL testing.

Figure I-2: Capacitor bank at DNB for DEL testing.

Figure I-3: Capacitor bank at DNB for DEL testing.

Figure I-4: Inductor at DNB for DEL testing.

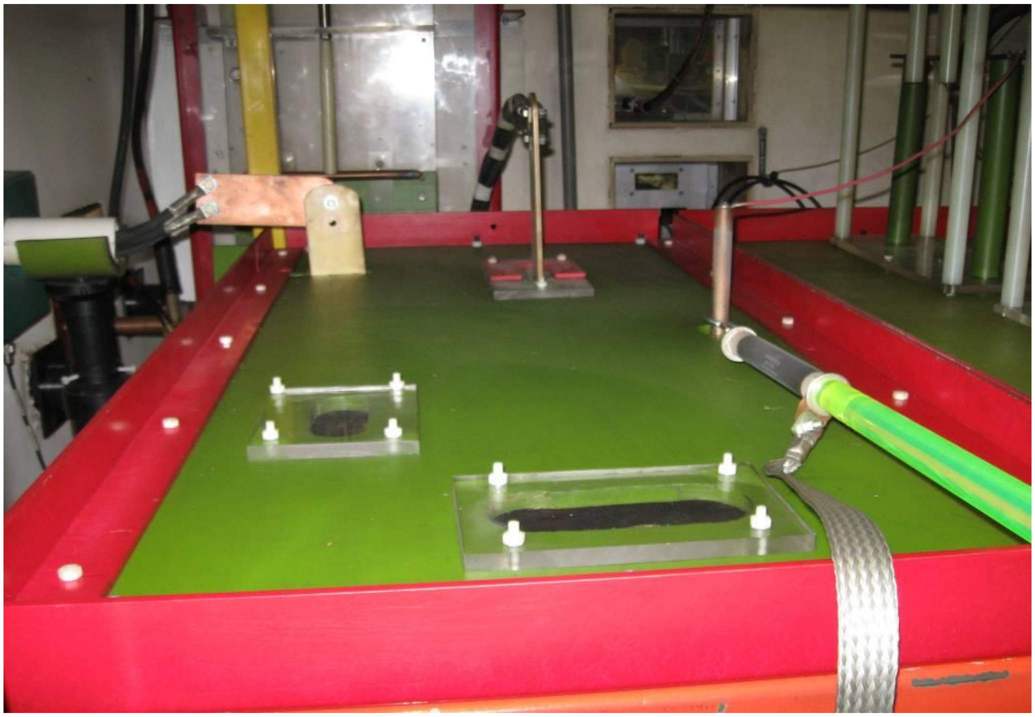


Figure I-5: Capacitor bank at DNB for DEL testing.

Figure I-6: DEL panel setup at DNB

Figure I-7: DEL panel LS-20 setup at DNB

Figure I-8: DEL panel LS-8 (rear) setup at DNB

Figure I-9: DEL panel (rear) setup at DNB.

Figure I-10: DEL panel (rear) setup at DNB.

Figure I-11: DEL panel setup at DNB.

Figure I-12: DEL panel (top view) setup at DNB.

Figure I-13: DEL panel (top view) setup at DNB.

Figure I-14: DEL panel setup at DNB.

Figure I-15: DEL panel setup (rear) at DNB.

Figure I-16: DEL panel setup (rear) at DNB.

Figure I-17: DEL panel after strike at DNB.

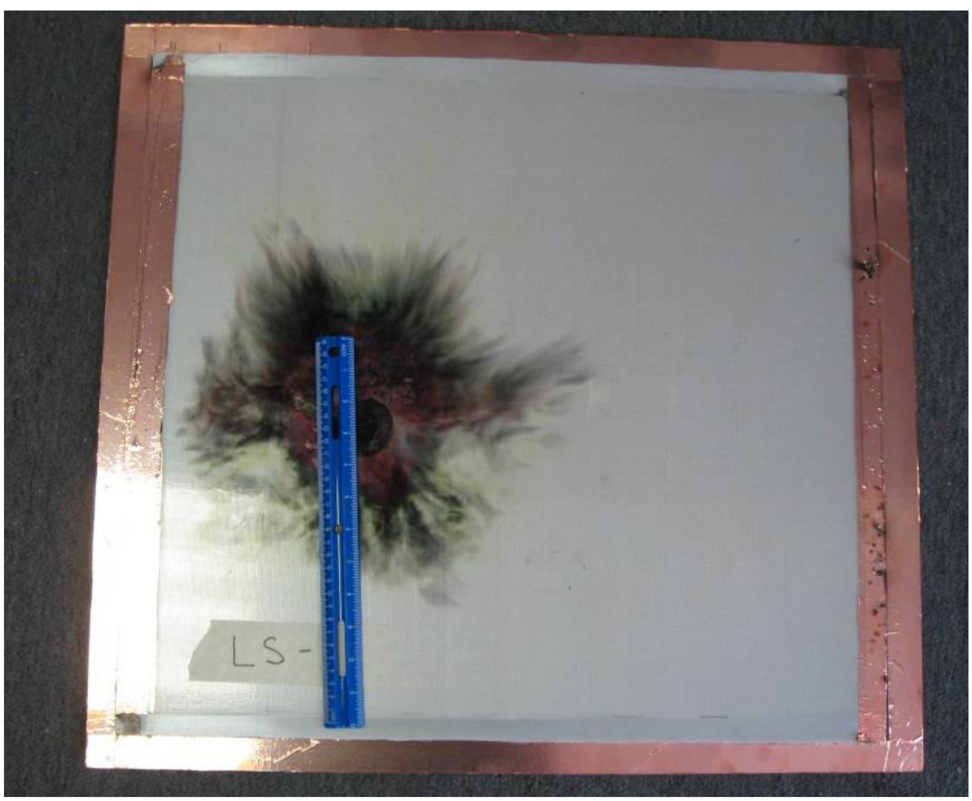


Figure I-18: Panel LS-1 after strike.

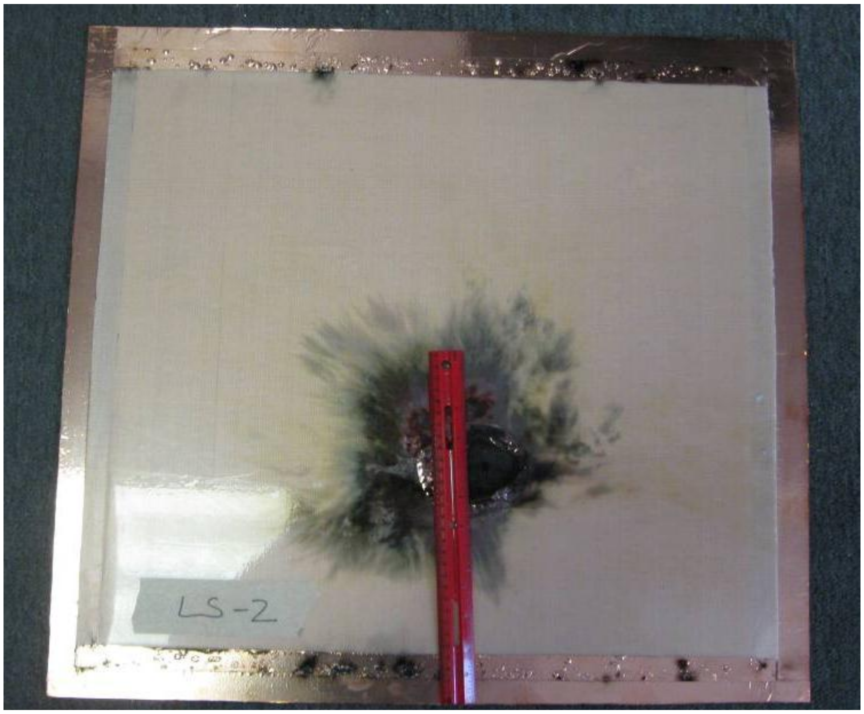


Figure I-19: Panel LS-2 after strike.

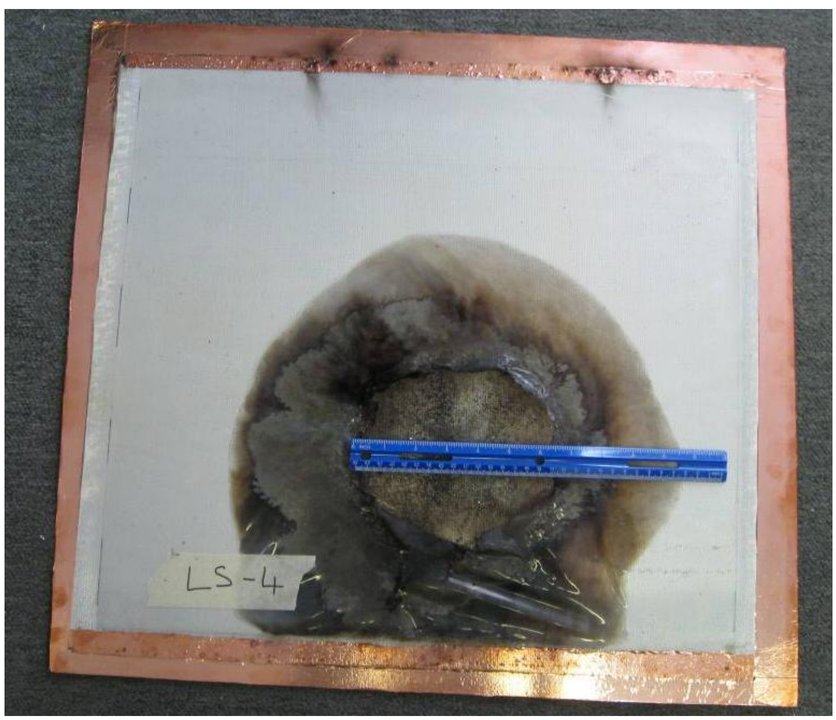


Figure I-20: Panel LS-4 after strike.

Figure I-21: Panel LS-5 after strike.

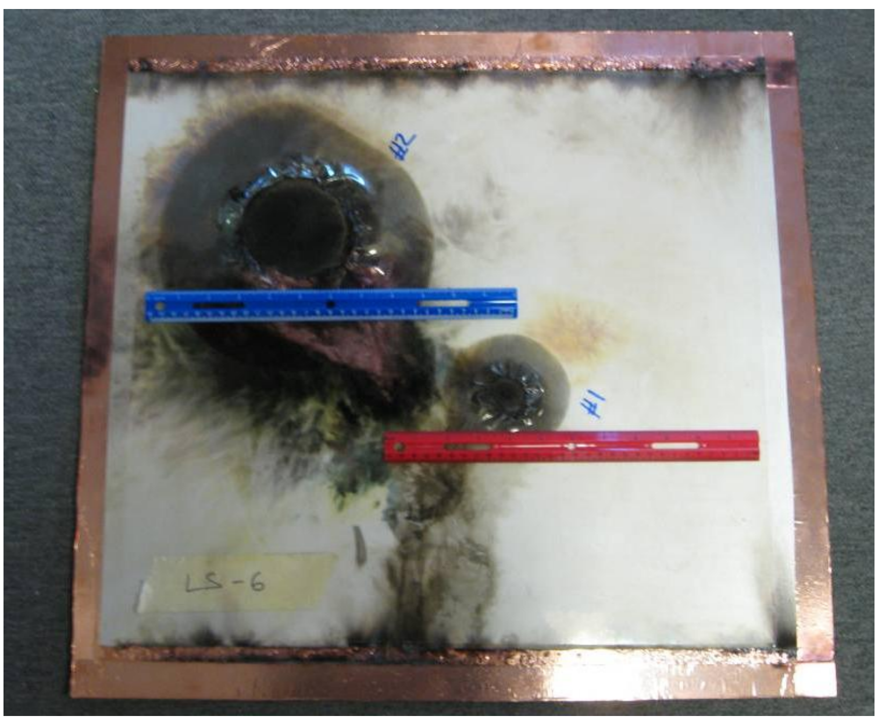


Figure I-22: Panel LS-6 after strike.

Figure I-23: Panel LS-7 after strike.

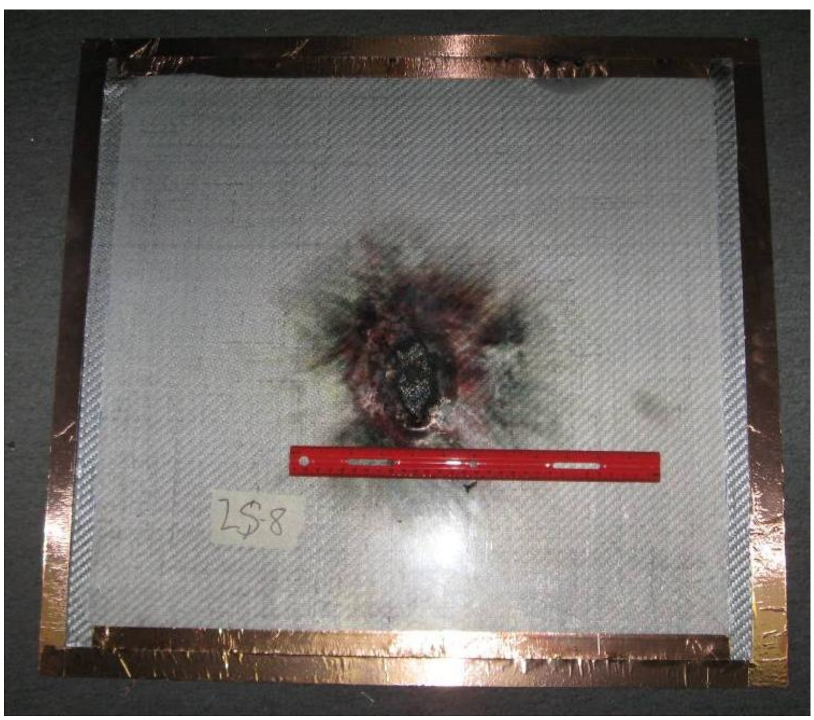


Figure I-24: Panel LS-8 after strike.

Figure I-25: Panel LS-9 after strike.

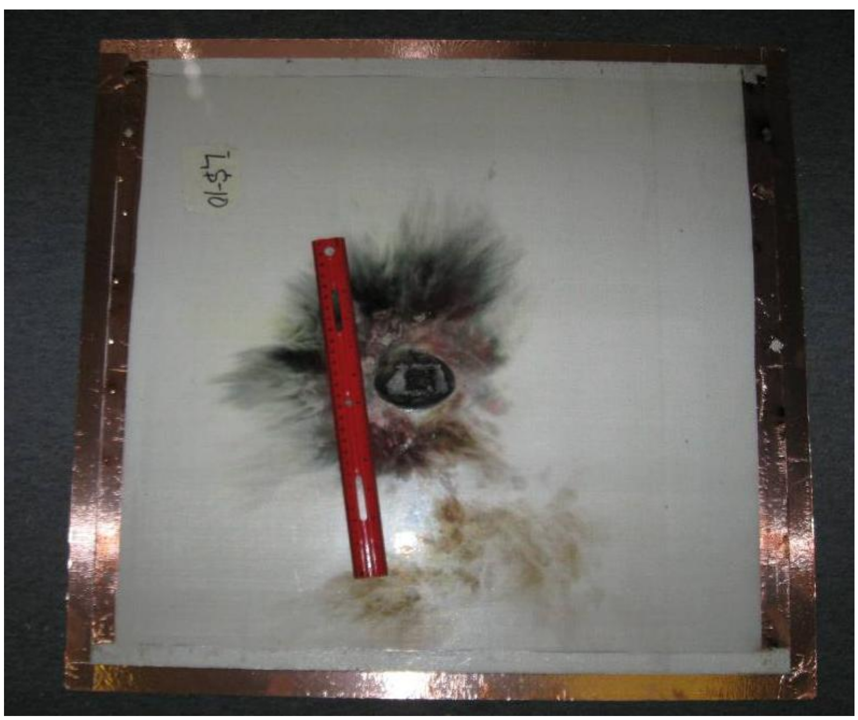


Figure I-26: Panel LS-10 after strike.

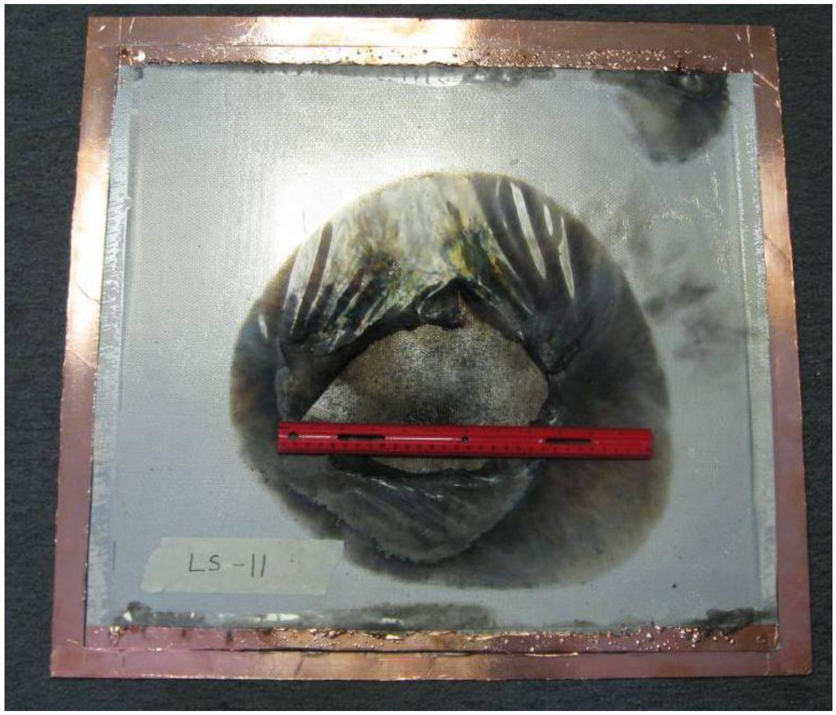


Figure I-27: Panel LS-11 after strike.

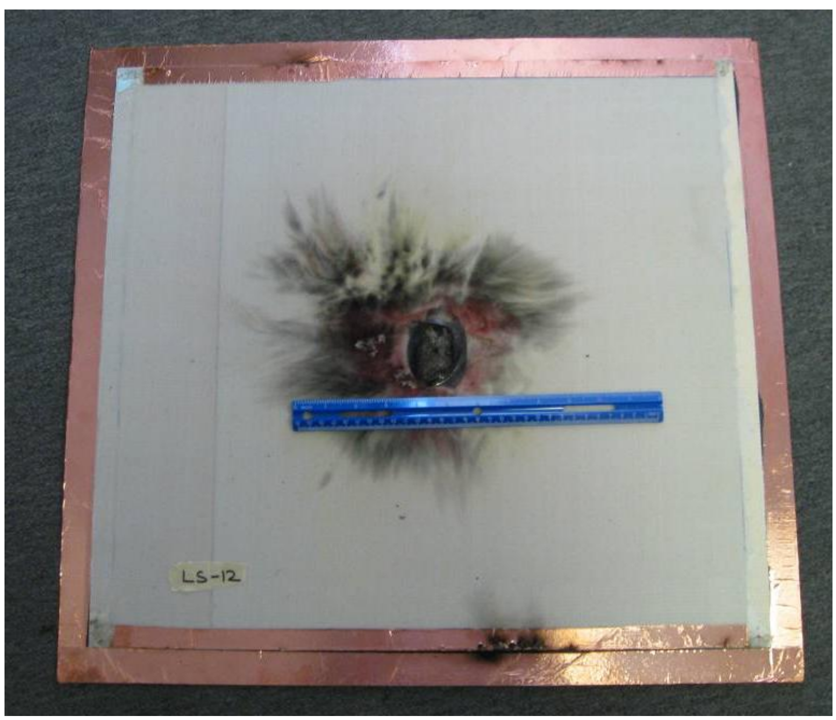


Figure I-28: Panel LS-12 after strike.

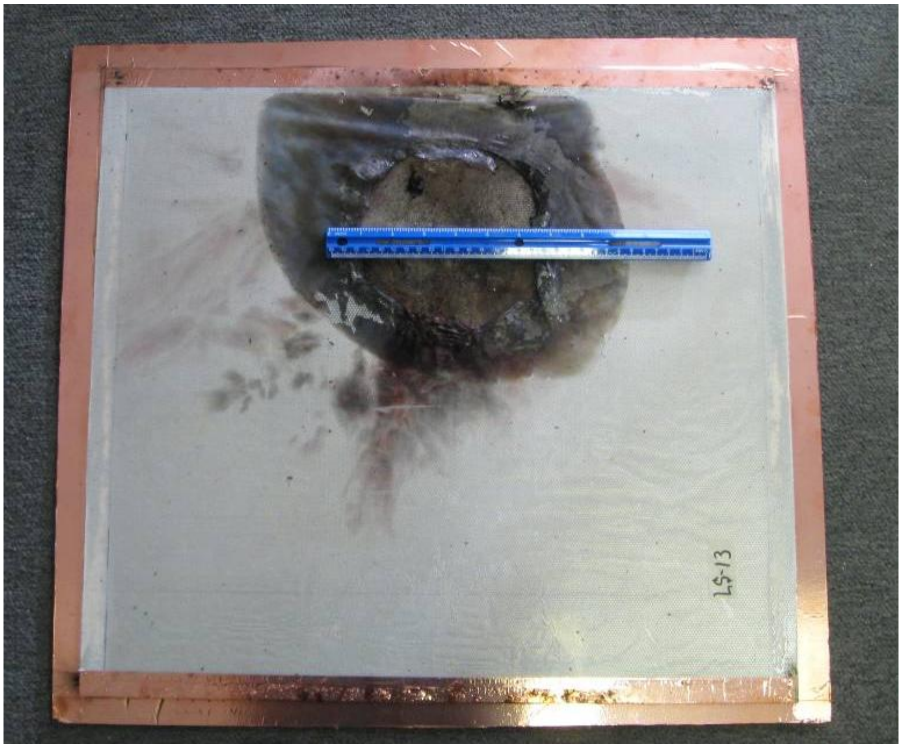


Figure I-29: Panel LS-13 after strike.

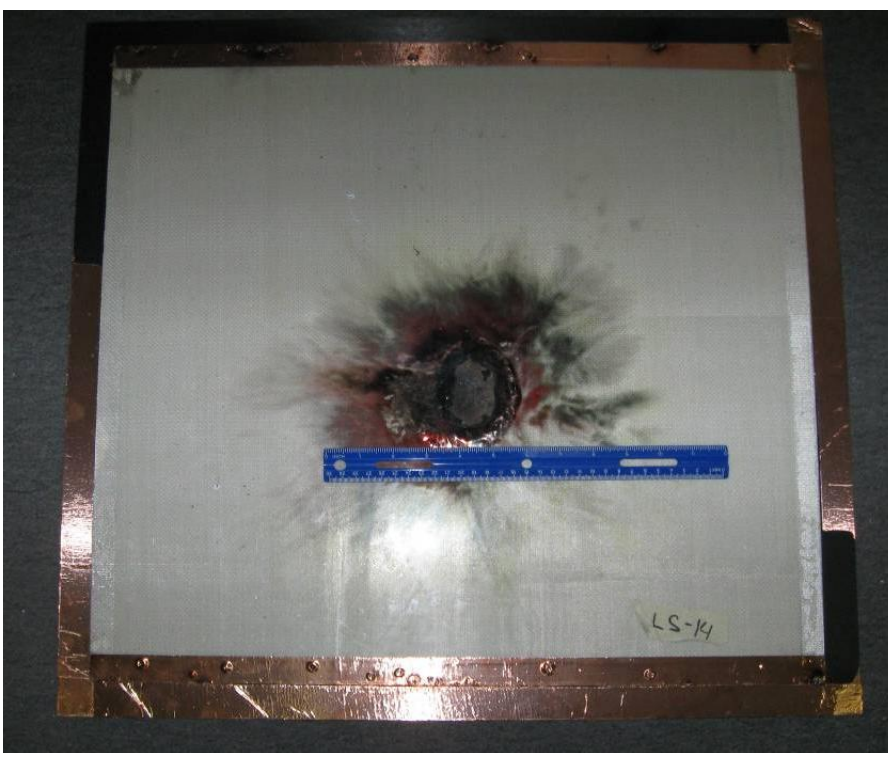


Figure I-30: Panel LS-14 after strike.

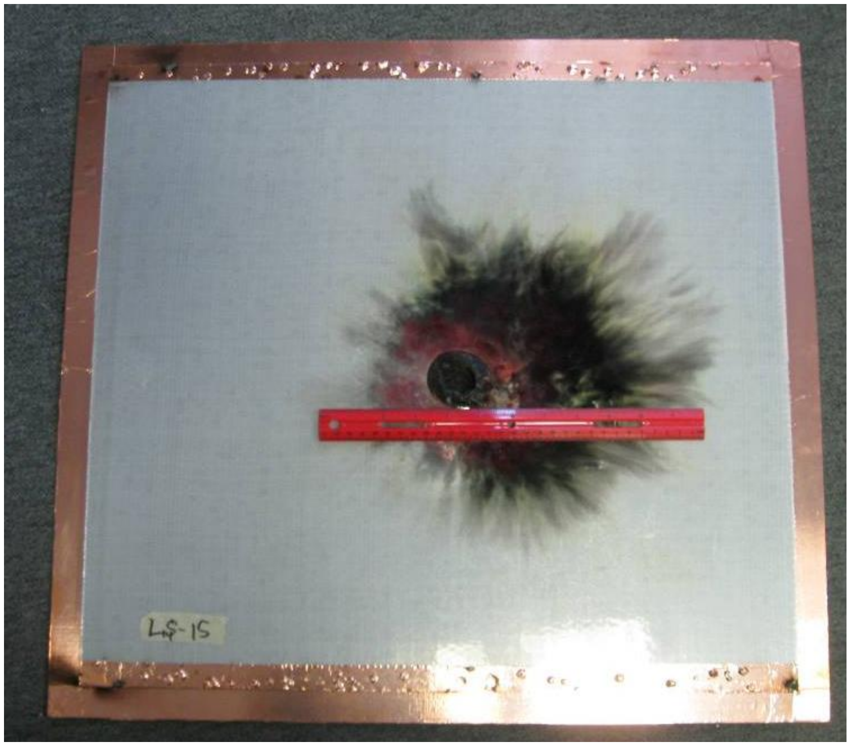


Figure I-31: Panel LS-15 after strike.

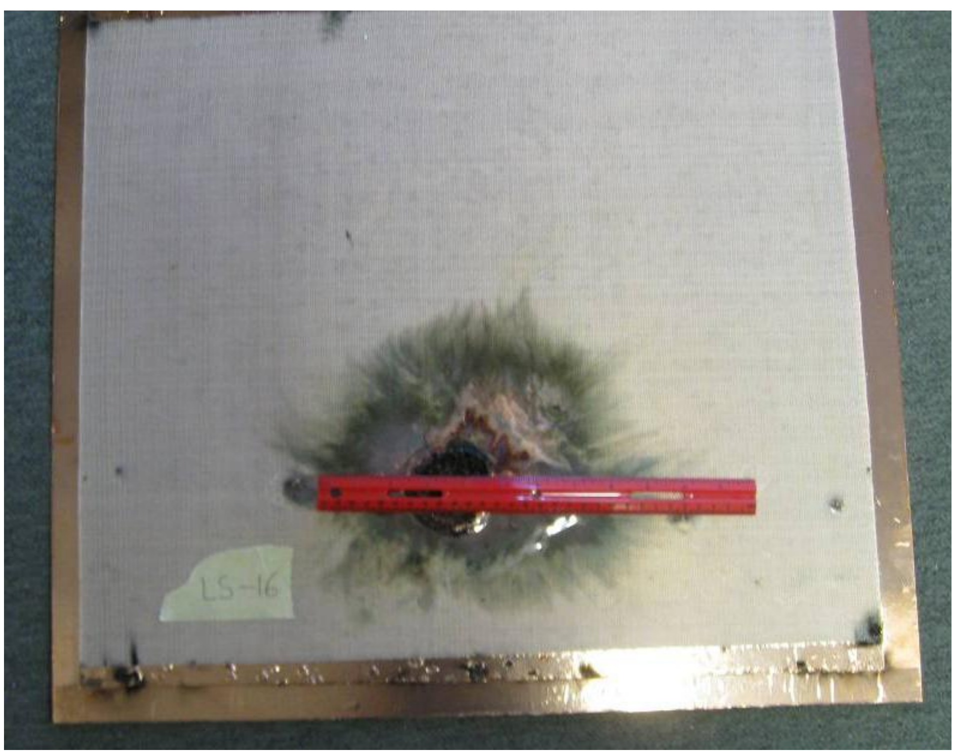


Figure I-32: Panel LS-16 after strike.

Figure I-33: Panel LS-18 after strike.

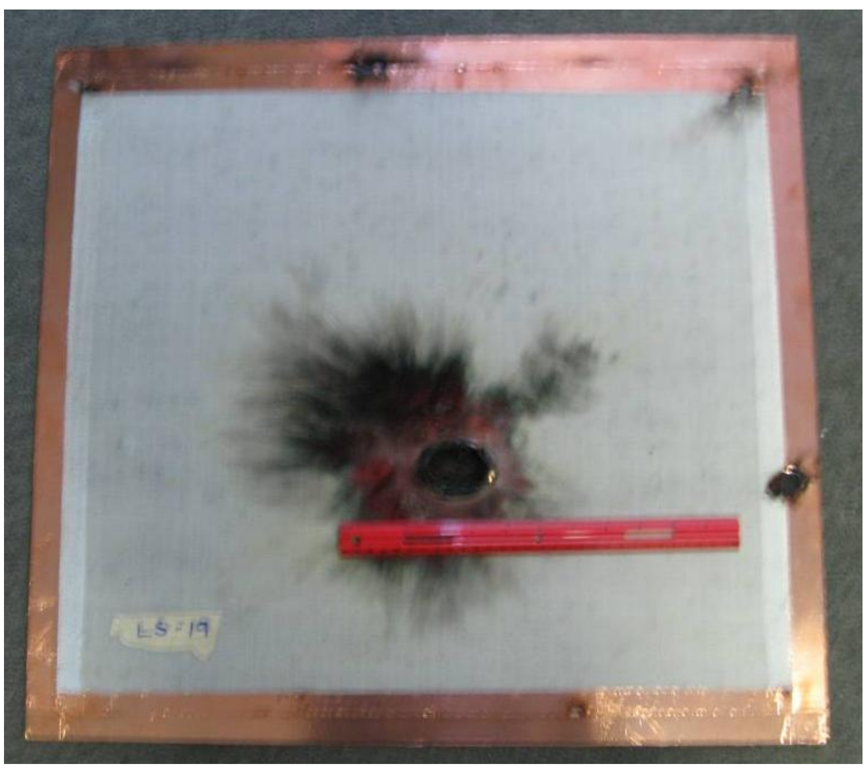


Figure I-34: Panel LS-19 after strike.

Figure I-35: Panel LS-20 after first strike.

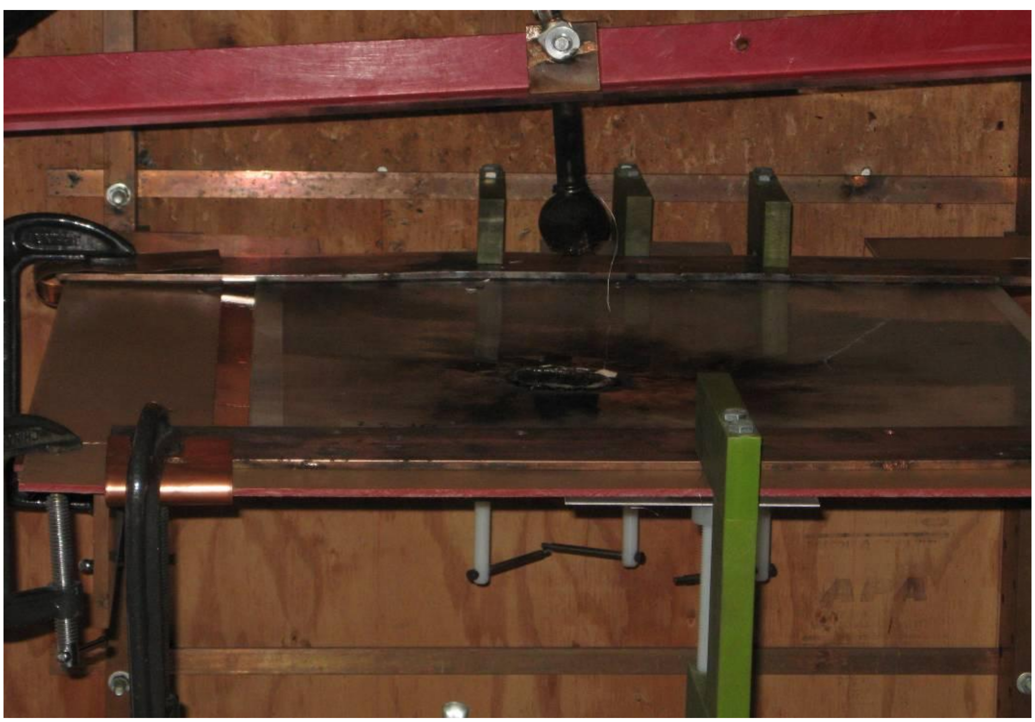


Figure I-36: Side view of panel LS-20 after first strike.

Figure I-37: Panel LS-20 after second strike.

Figure I-38: Panel LS-22 after strike.

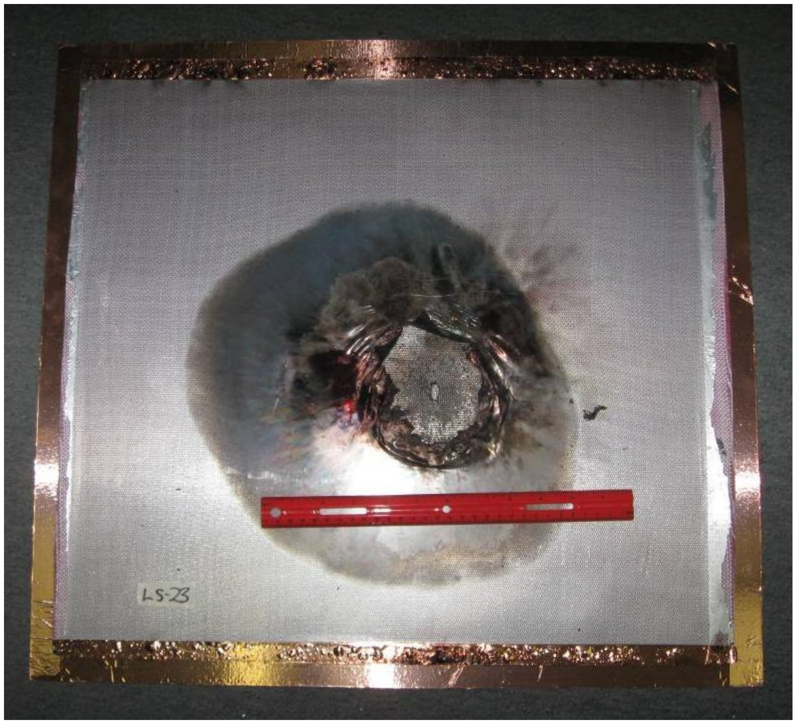


Figure I-39: Panel LS-23 after strike.

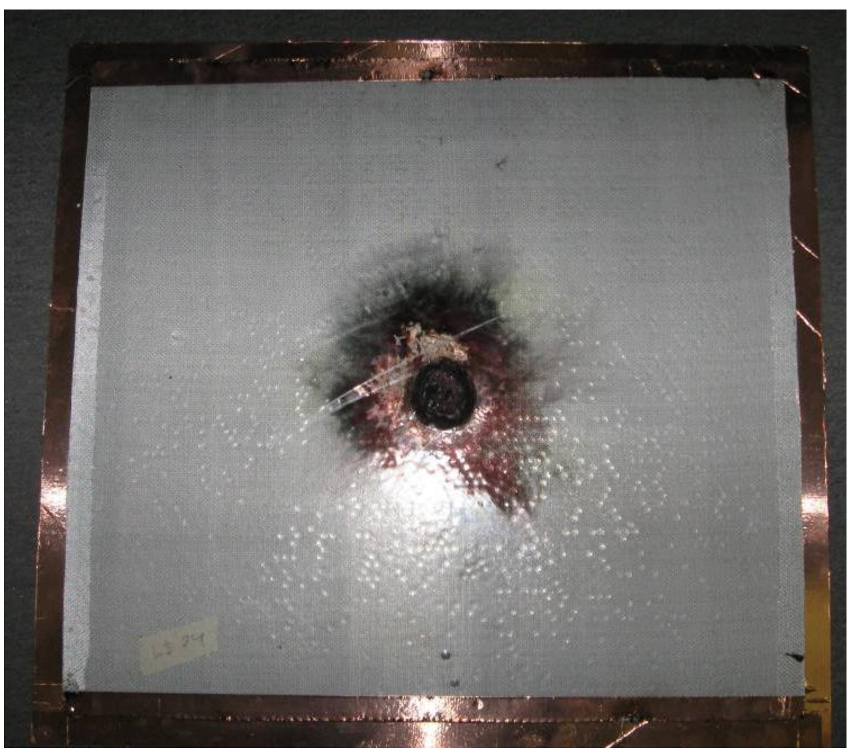


Figure I-40: Panel LS-24 after strike.

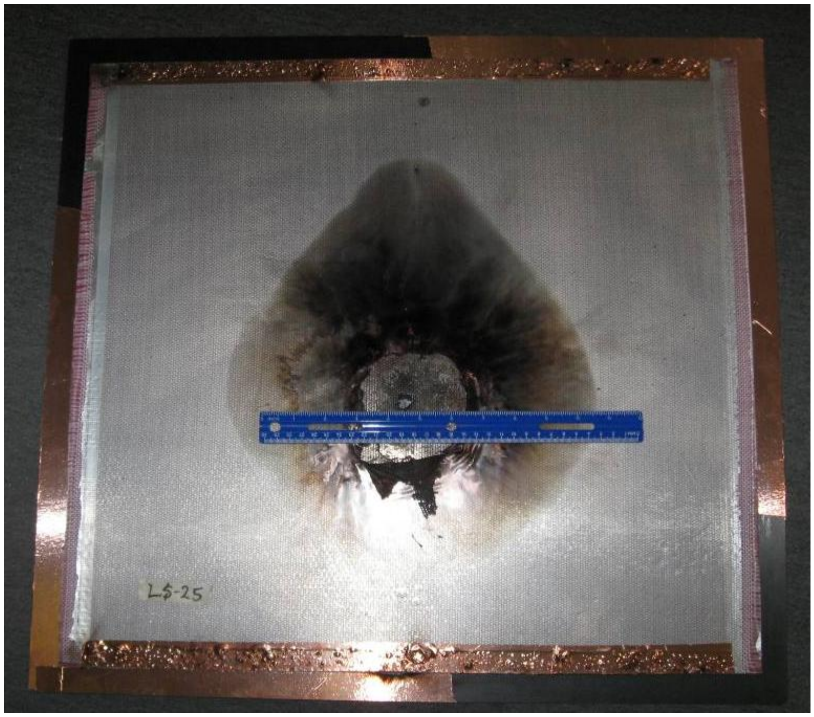


Figure I-41: Panel LS-25 after strike.

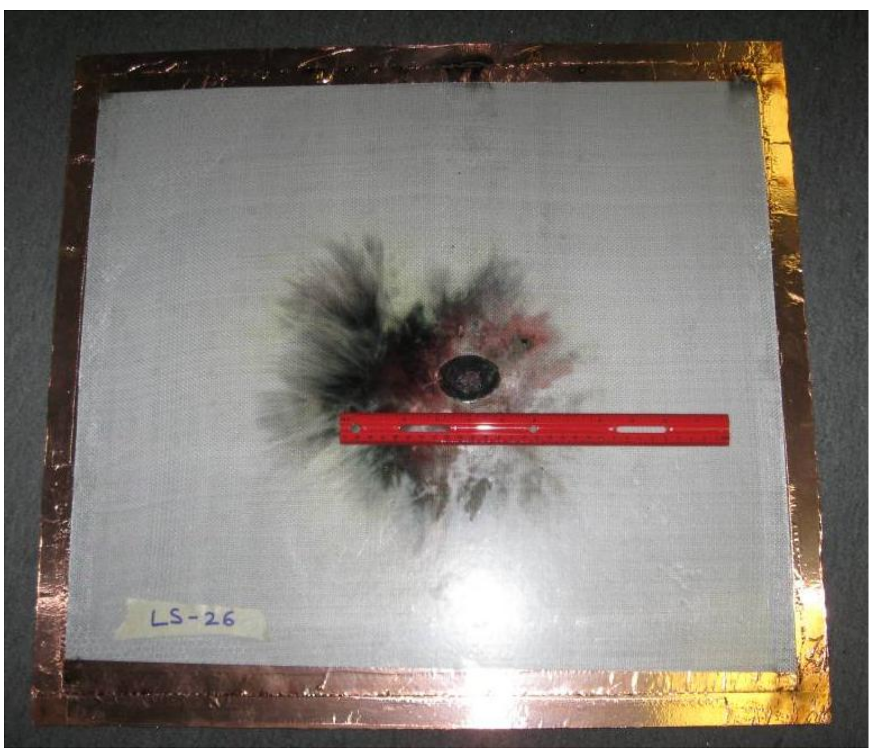


Figure I-42: Panel LS-26 after strike.

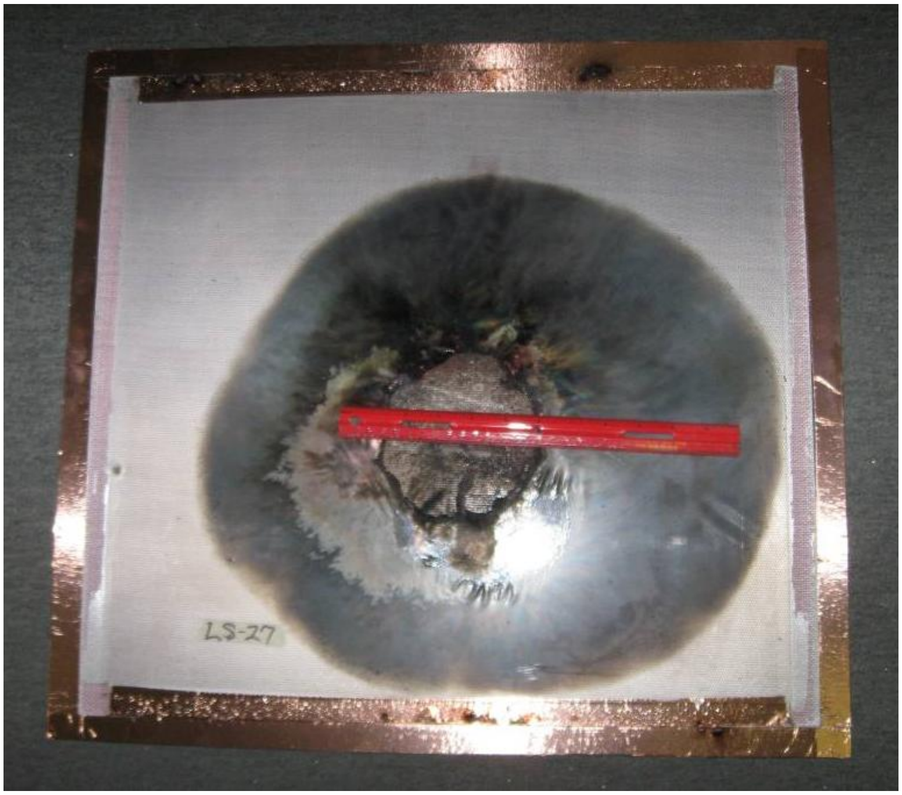


Figure I-43: Panel LS-27 after strike.

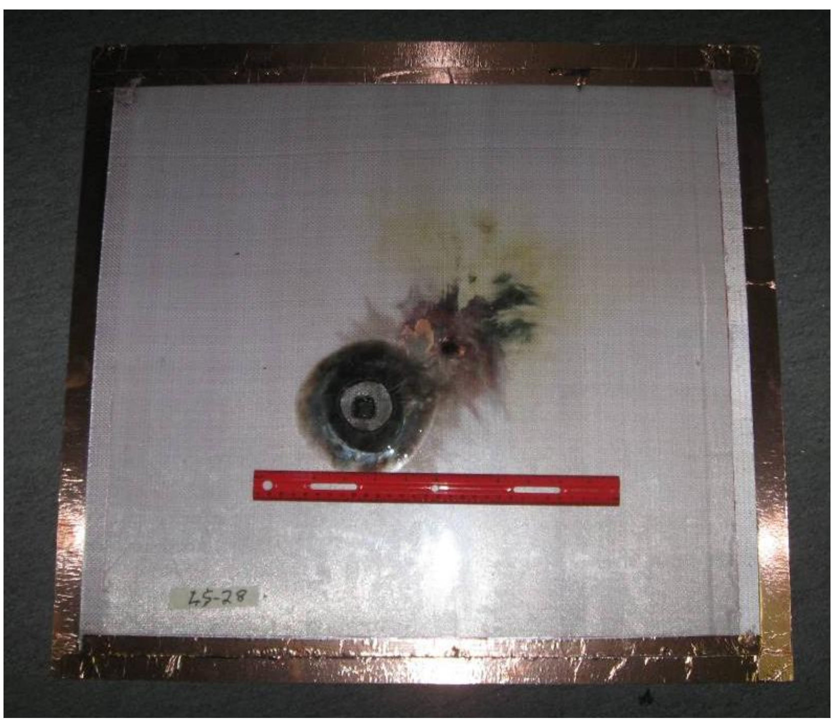


Figure I-44: Panel LS-28 after strike.

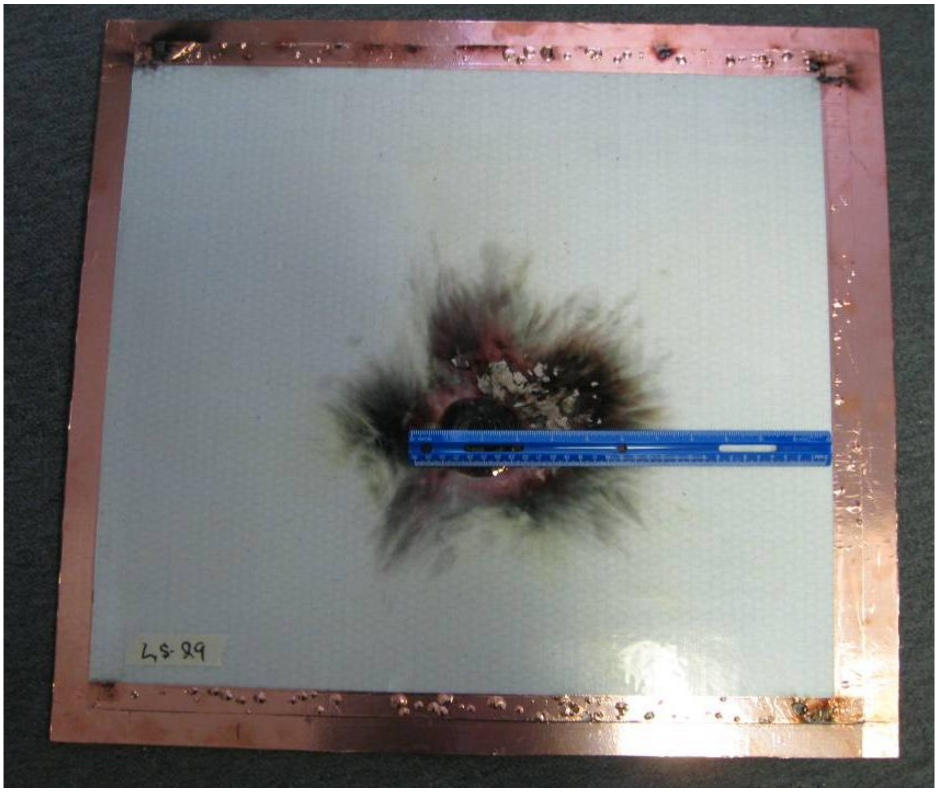


Figure I-45: Panel LS-29 after strike.

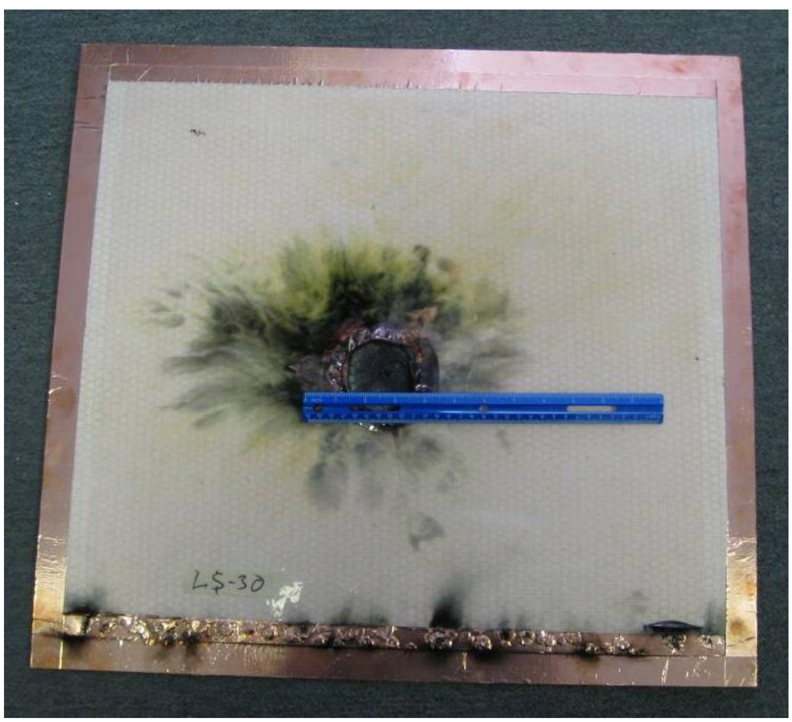


Figure I-46: Panel LS-30 after strike.

Figure I-47: Panel LS-32 after strike.

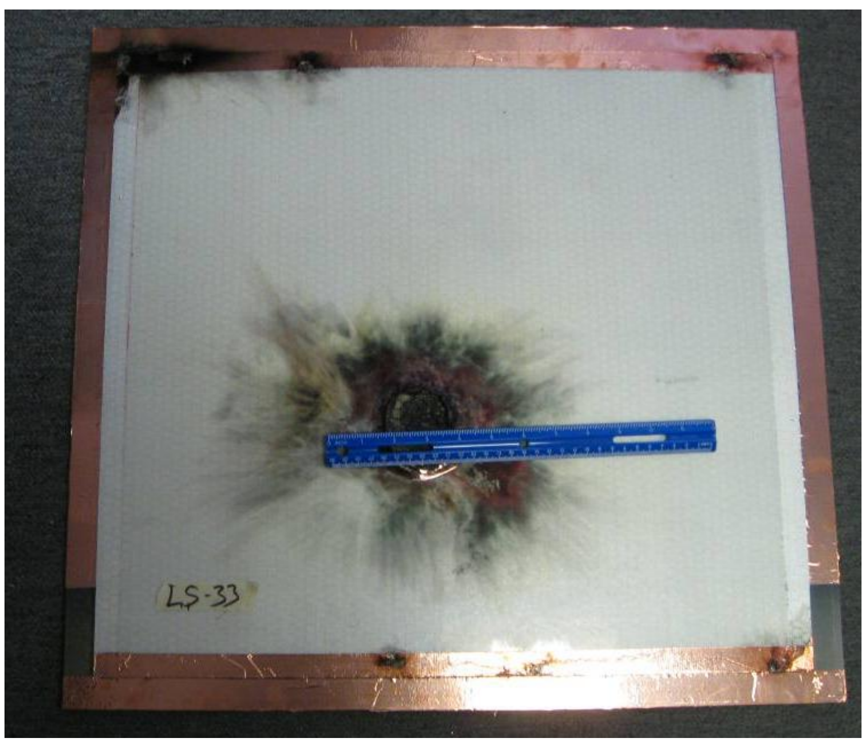


Figure I-48: Panel LS-33 after strike.

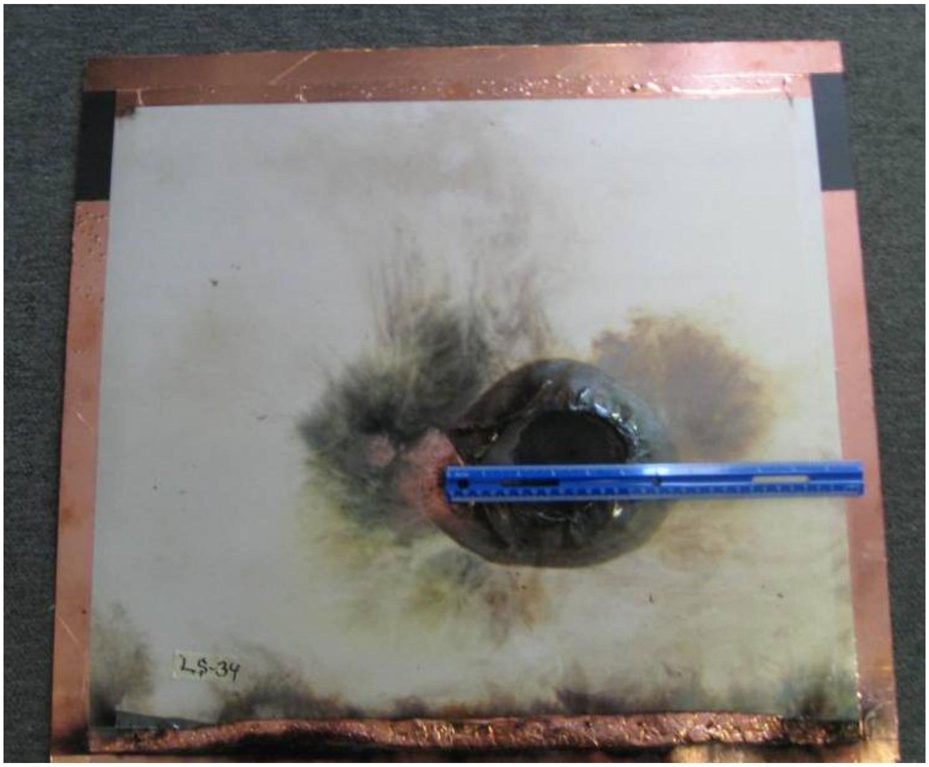


Figure I-49: Panel LS-34 after first strike.

Figure I-50: Panel LS-34 after second strike (100 kAmps and 200 kAmp).

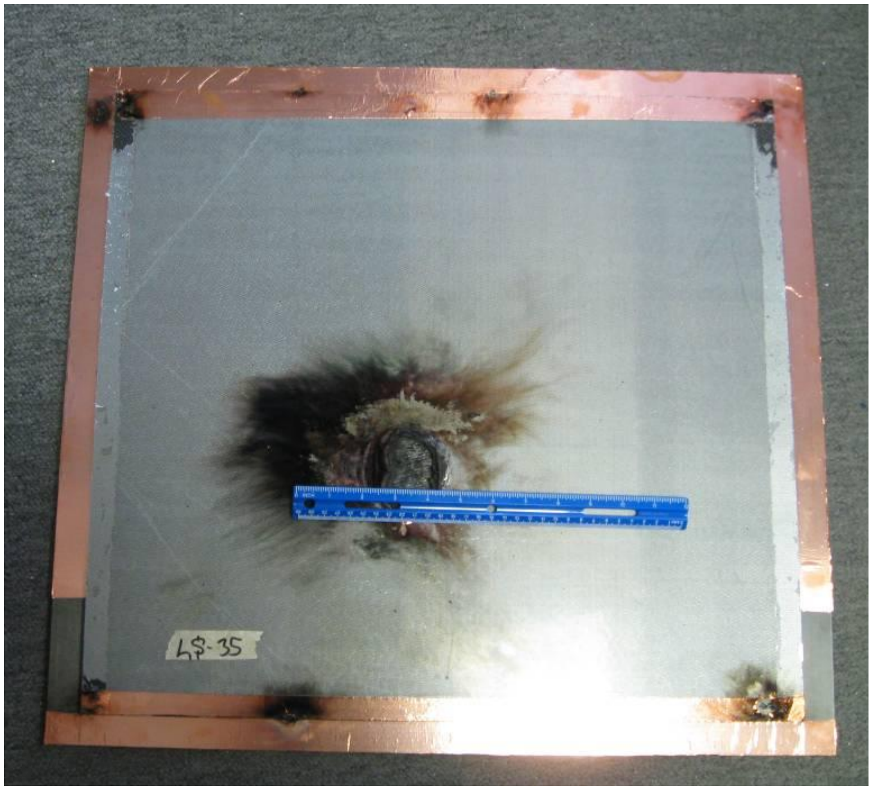


Figure I-51: Panel LS-35 after strike.

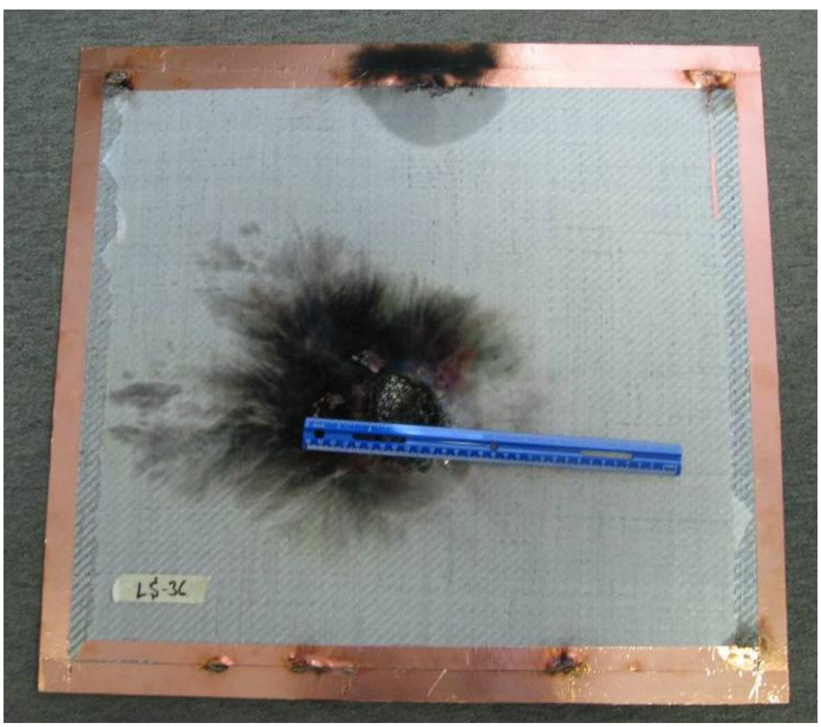


Figure I-52: Panel LS- 36 after strike.

Figure I-53: Panel LS-37 after strike.

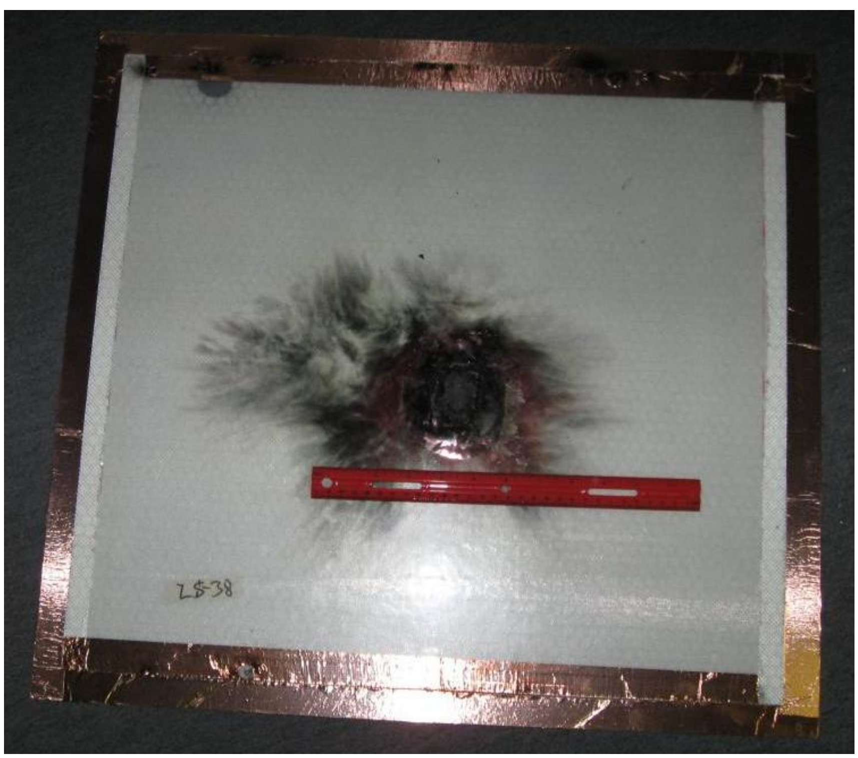


Figure I-54: Panel LS-38 after strike.

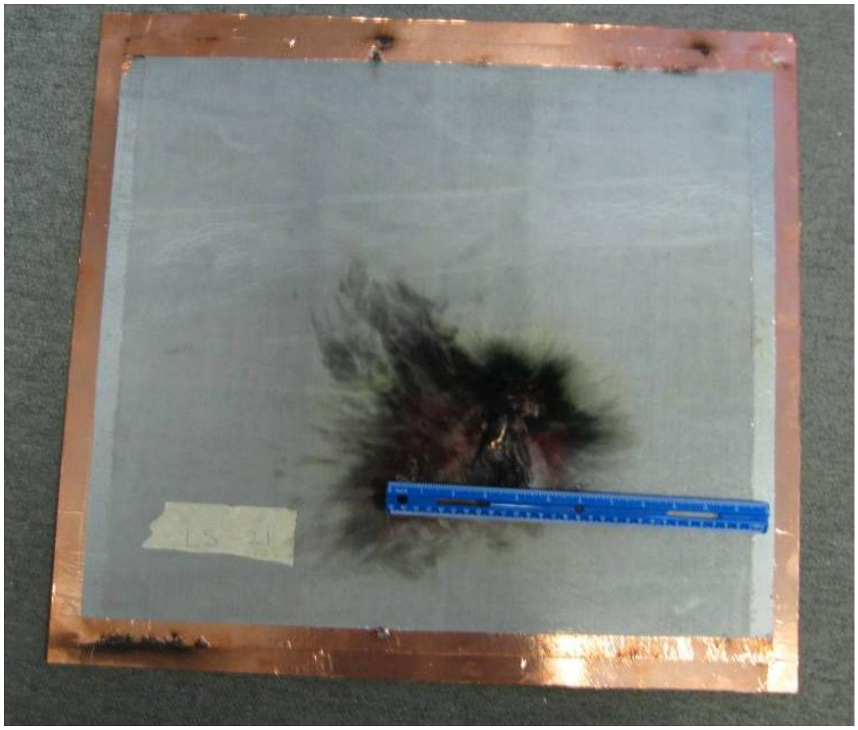


Figure I-55: Panel LS-39 after first strike.

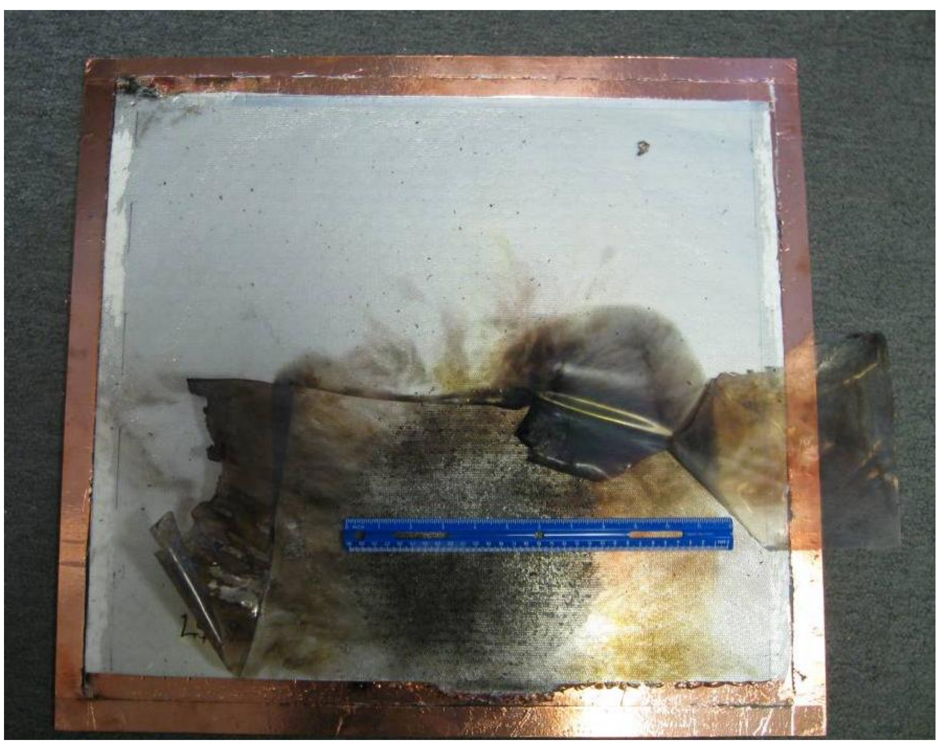


Figure I-56: Panel LS-39 after second strike.

Figure I-57: Panel LS-39 after second strike (100 kAmps and 200 kAmps).

Figure I-58: Panel LS-40 after strike.

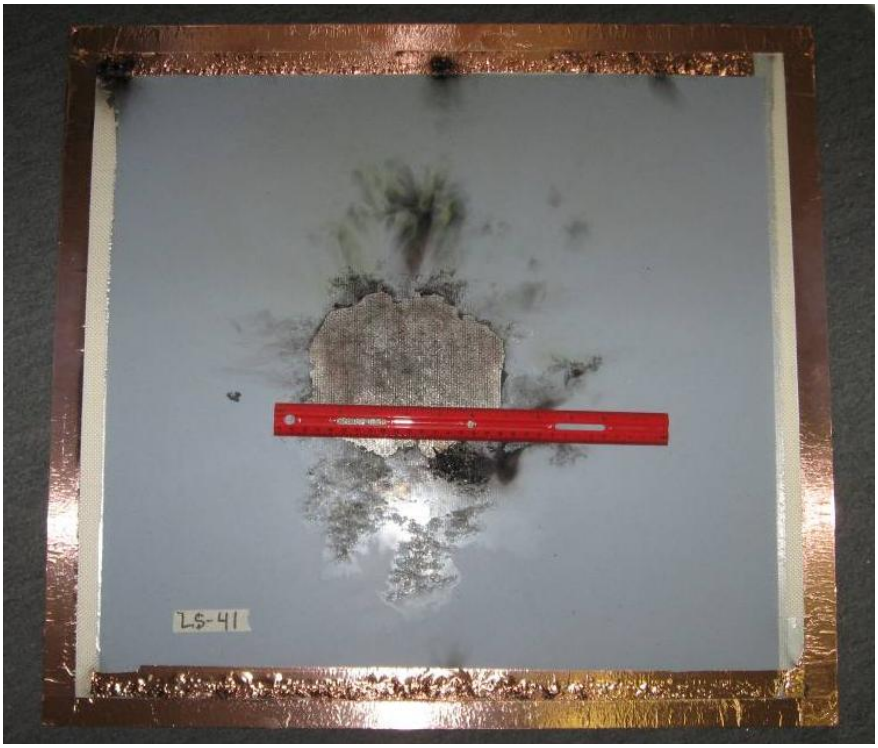


Figure I-59: Panel LS-41 after strike.

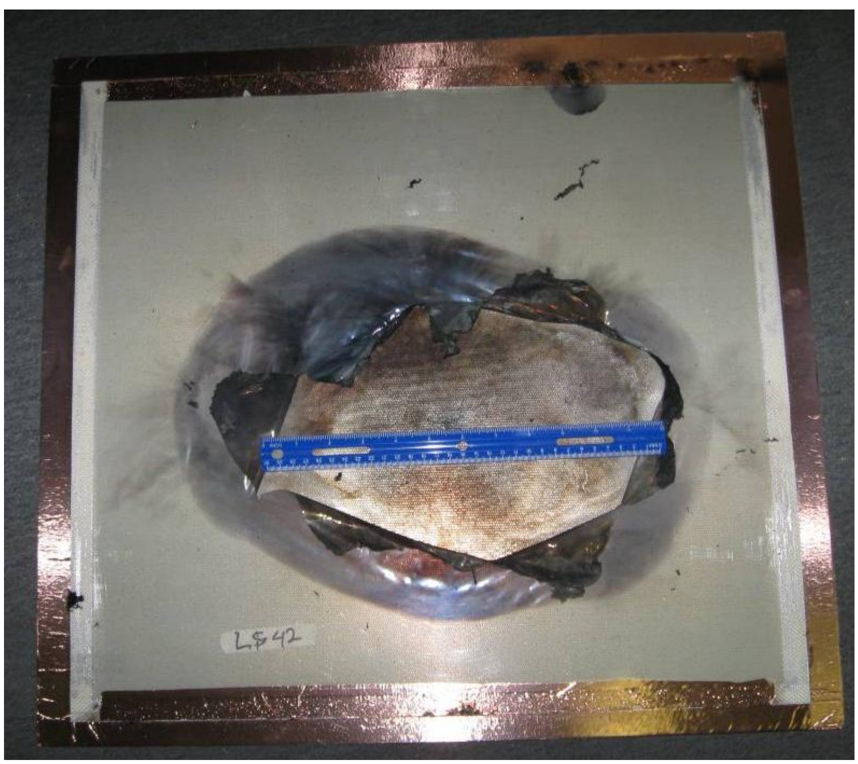


Figure I-60: Panel LS-42 after strike.

Figure I-61: Panel LS-43 after strike.

Figure I-62: Panel LS-43 after strike.

Figure I-63: Panel LS-44 after strike.

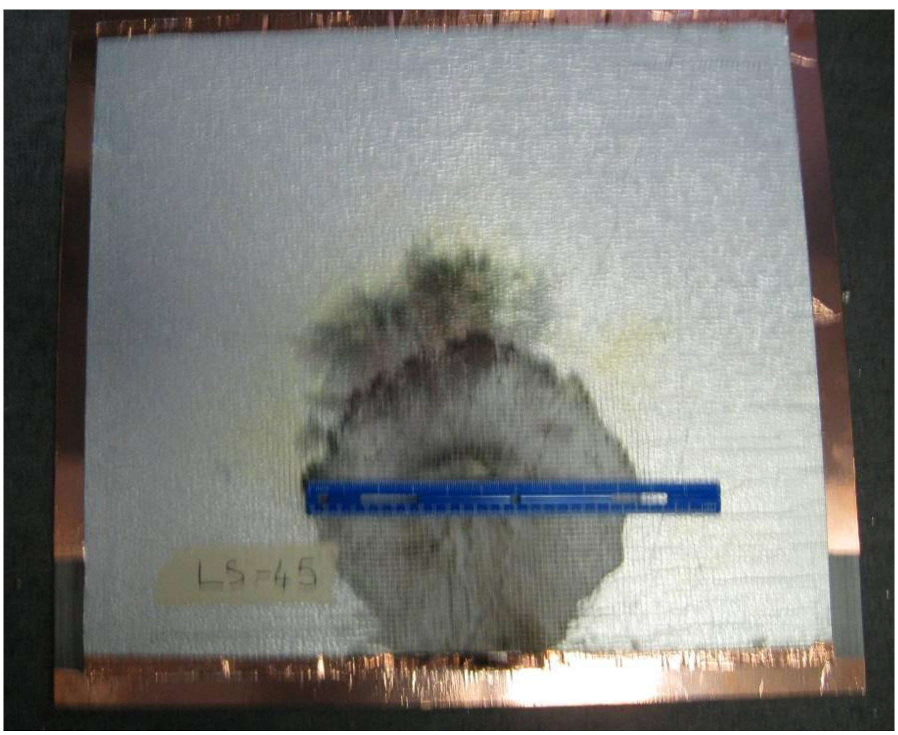


Figure I-64: Panel LS-45 after strike.

Appendix J
Second-Generation Thermography Report

REPORT TITLE:	NDI of NASA STAR-C^2 Test Article CFRP Panels (Phase Two)		
Report #:	13-359-004	Date:	January 8, 2013
To:	Vicki Johnson	From:	Michael Daehling
cc:	S. Brown	I. Nelson	
Approved by:	Jay Amos		

Subject Information

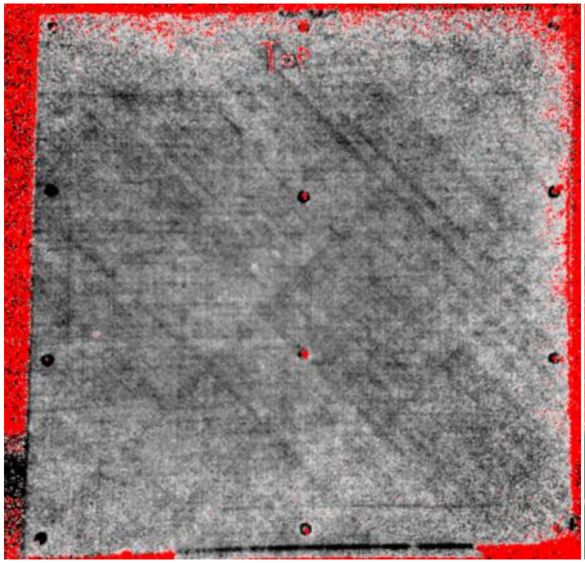
P/N:	NASA PANEL 1 and 2 NASA STAR-C^2 Test Articles	S/N:	See table I
Part description:	5 plies Uni 45/90 12k-145-UNI Outer plies 3k-193-PW (~.043" CPT): Oven-cured Per SX512110 Material: CMAC004	Model:	NA
Inspector	M. Daehling, J. Amos	Charge #:	E-NNC10CA36C
Inspector Level	Trainee & 3		
Material Type	NCT321-G150/NAS-S-12K-UNI		
Type of Inspection	Pulse Echo & Thermography (IRT)		

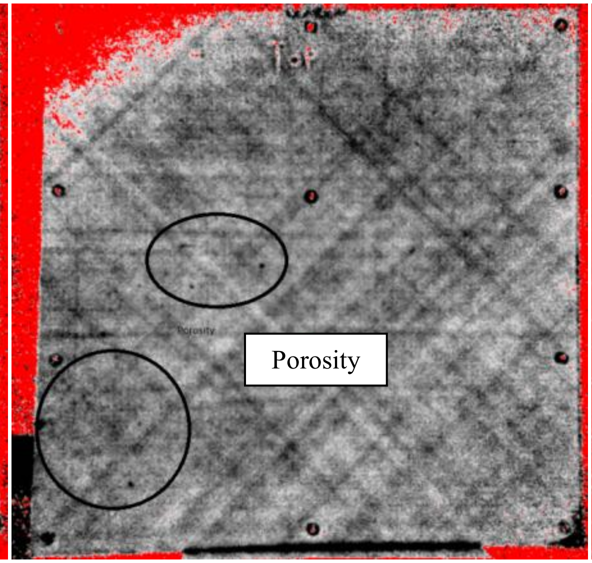
Infrared Thermography (Flash method) was performed on the panels with a modified 4 lamp flash hood and graded per CSTI009.

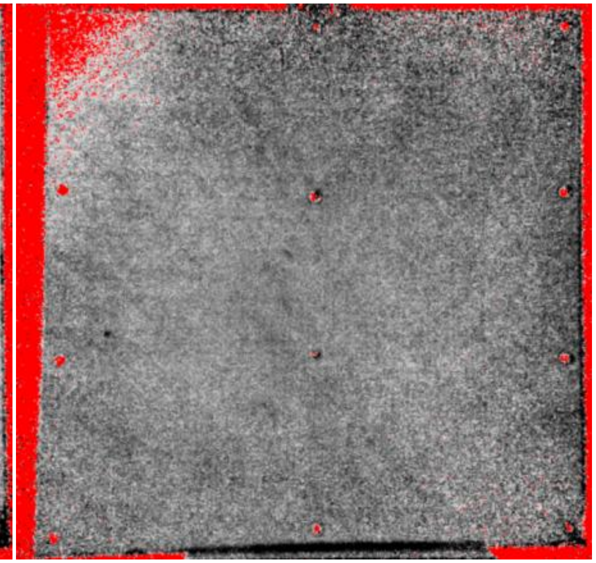
Table I
Test Panel NDI Results

Panel	Initial Passing Level	Pre-test Condition	Post-test Delamination (sq.in.)		Panel	Initial Passing Level	Pre-test Condition	Post-test Delamination (sq.in.)
18129		Porosity	2.3, 1.5, 1.3 2.5, 2.5, 2.0 2.6. 1.7, 1.4					
18141	1				18170	2	Porosity center splices	No delams post-strike
18154	2	Porosity along splices			18171	2	Porosity center splices	
18155	1				18172	1		
18156	1				18186	2	Porosity center splice	
18157	2	Porosity center splices			18187	2	Porosity center splices	
18158	2	Porosity center splices			18188	2	Porosity center splices	
18159	2	Porosity on SW splice			18189	2	Porosity center splices	
18160	2	Porosity center splices			18190	2	Porosity along splices	
18161	1	Porosity center splices	No delams post-strike		18191	2	Porosity along splices	
18162	3	Voids - Porosity along splices	No delams or change in pre-existing voids*		18200	1		0.2, 0.7
18163	3	Porosity along splices	No delams post-strike		18201	2	1 Void	0.24, 1.26, 2.8; no change in pre-existing void
18164	1				18202	3	2 Voids	0.07, 0.38; no change in pre-existing void
18165	2	Porosity center splices			18829	1		0.35, 0.48, 0.15, 0.12, 1.68, 0.56, 0.12
18166	1				18830	1		0.32, 0.32, 0.18, 0.27, 0.24, 0.27, 1.44, 0.32, 0.28
18167	1				18831	2	1 Void	0.61, 0.61, 0.61, 0.61, 0.74, 0.38, 0.38
18168	2	Porosity along splices	No delams post-strike					
18169	2	Porosity along splices	1.05					

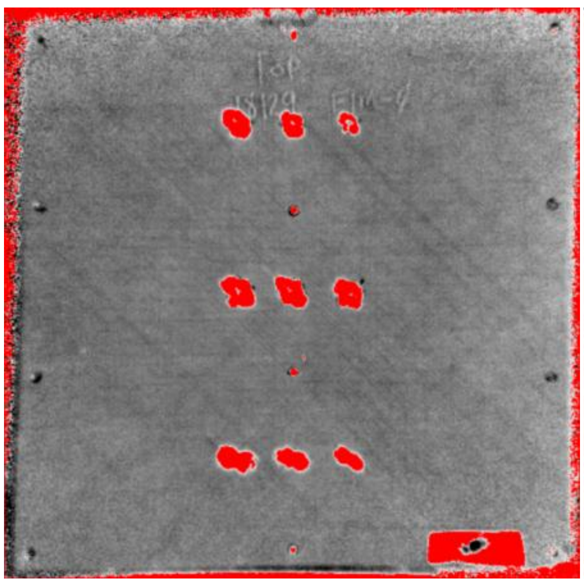
* Voids in protective skin adhesive appear smaller & changed position, possibly due to heat generated during strike test.

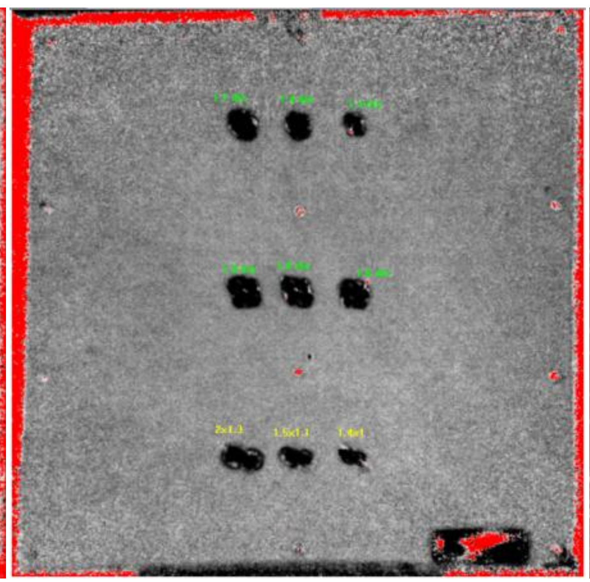


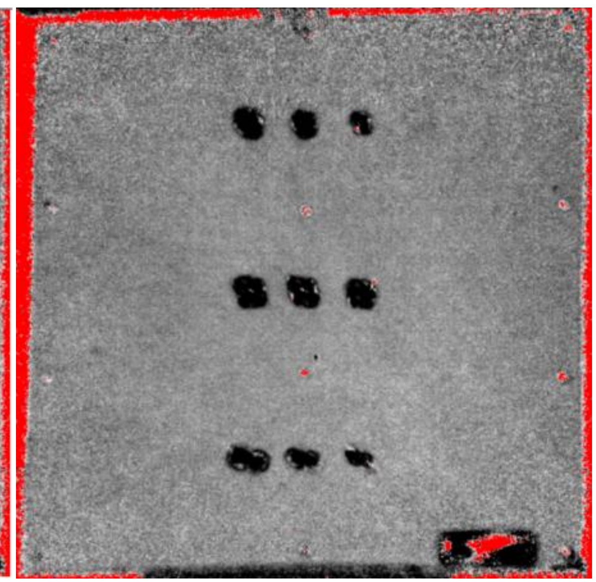




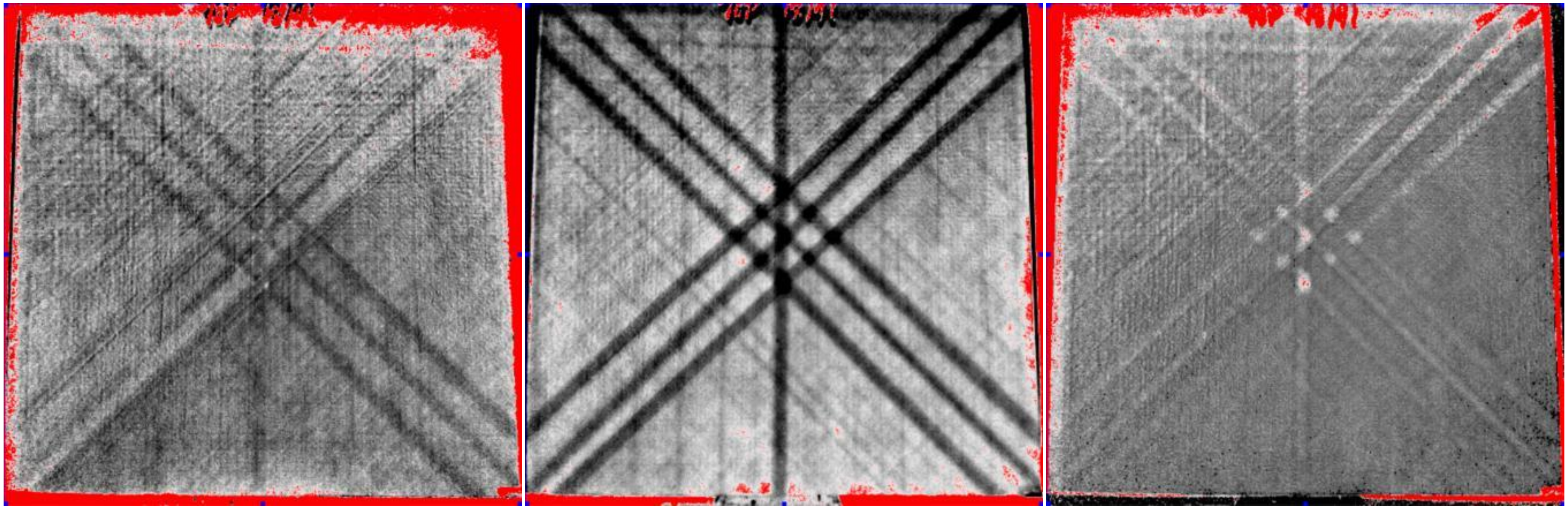
SN 18129 1d 0.42s SN 18129 1d 1.0s porosity SN 18129 2d PA



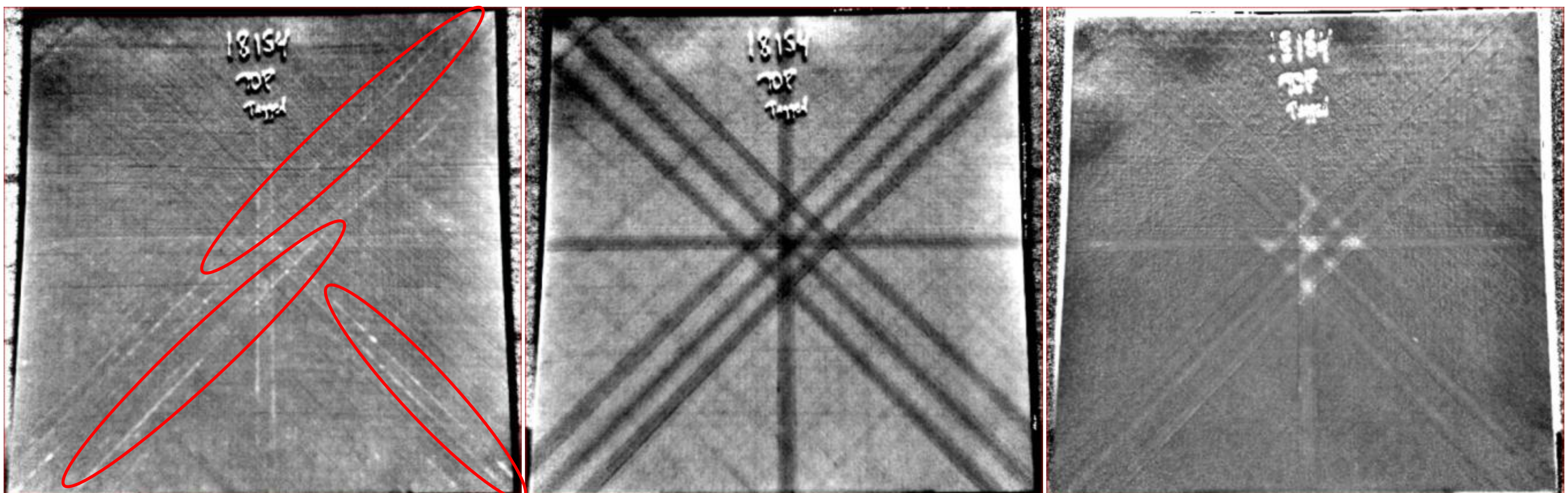




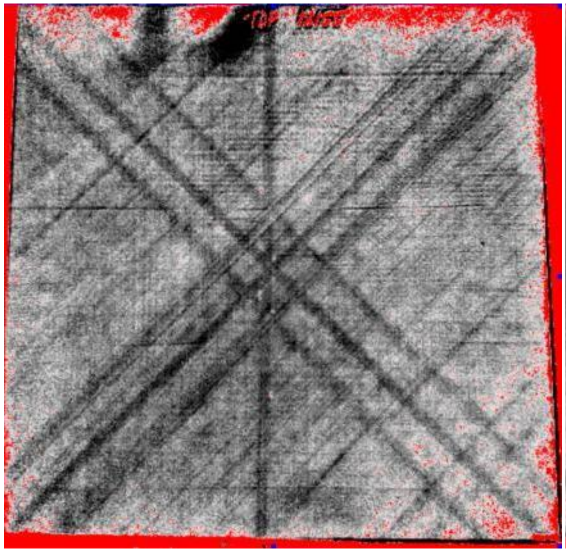
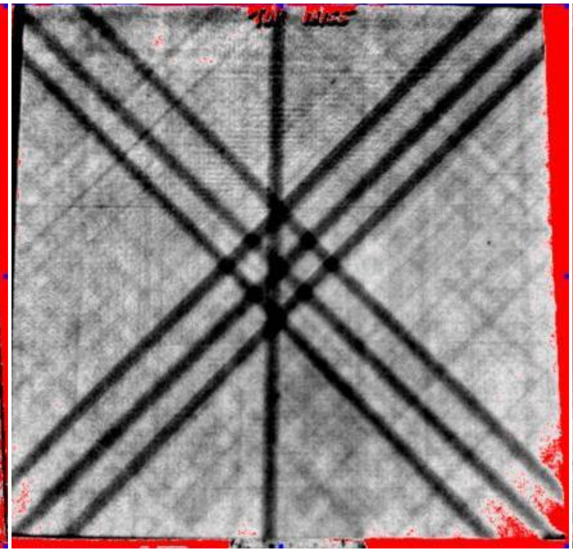
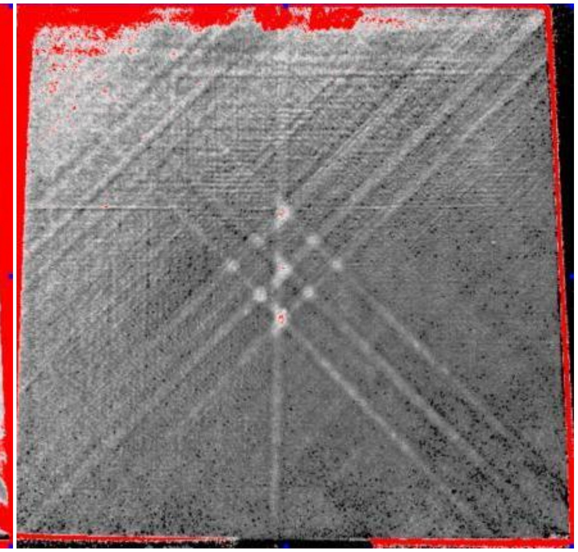
SN 18129 1d 0.42s Post Impact SN 18129 1d 1.0s voids Post Impact SN 18129 2d PA Post Impact



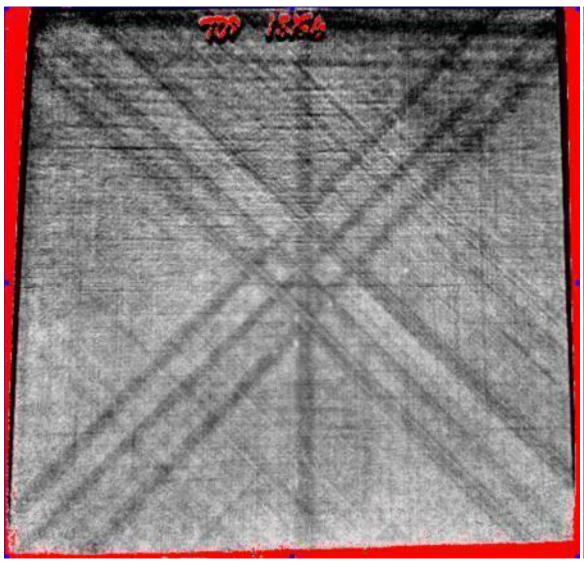
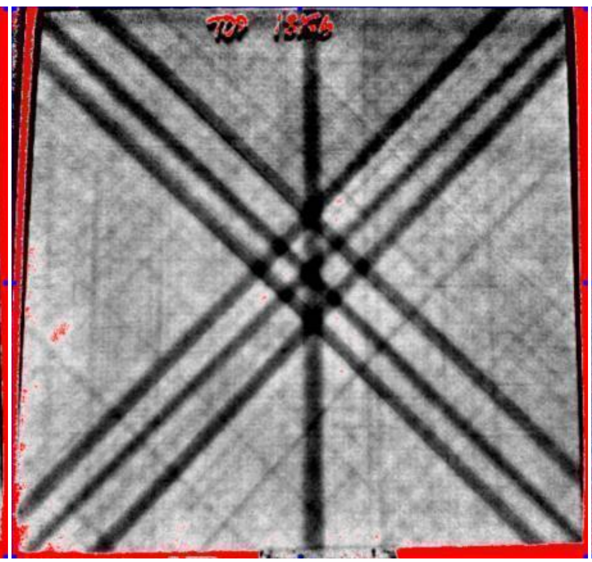
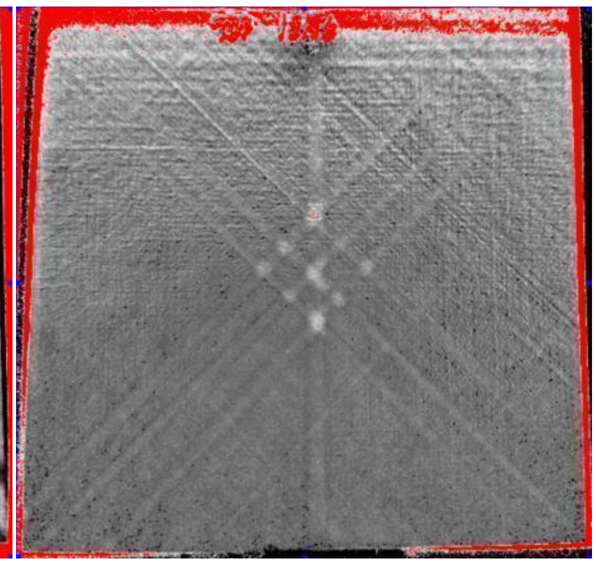
SN 18141 1d 0.42s SN 18141 1d 1.0s SN 18141 2d PA



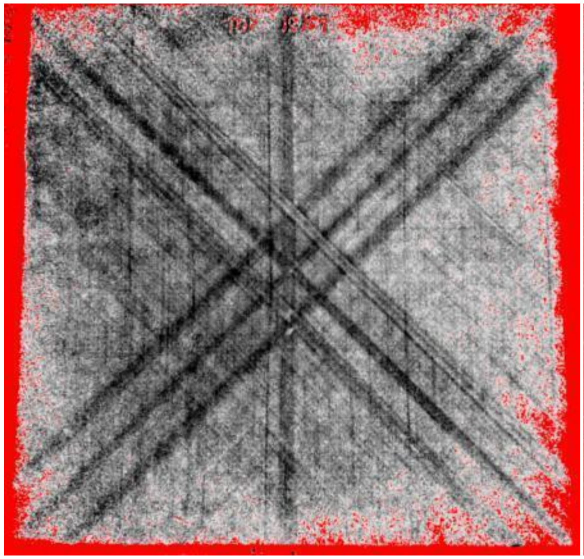
SN 18154 1d 0.42s SN 18154 1d 1.0s SN 18154 2d PA

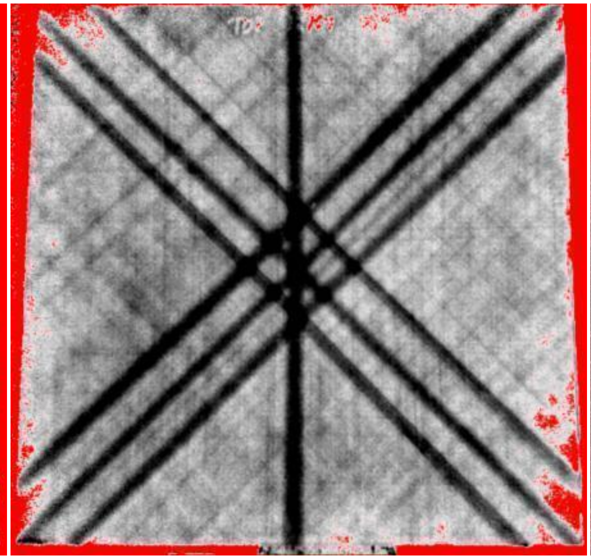
SN 18155 1d 0.42s SN 18155 1d 1.0s SN 18155 2d PA

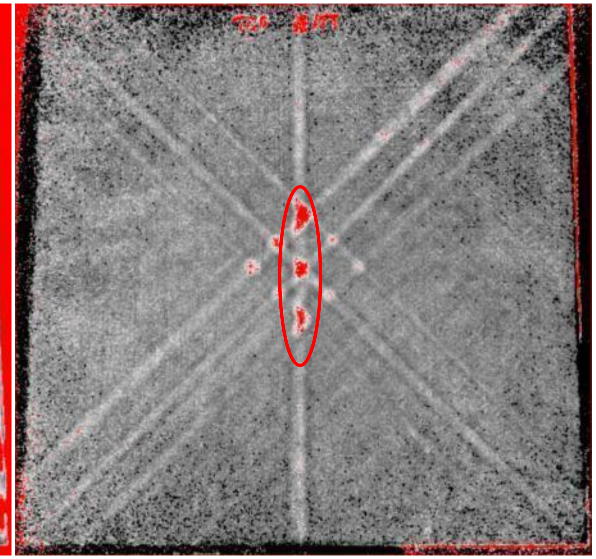
SN 18156 1d 0.42s SN 18156 1d 1.0s SN 18156 2d PA



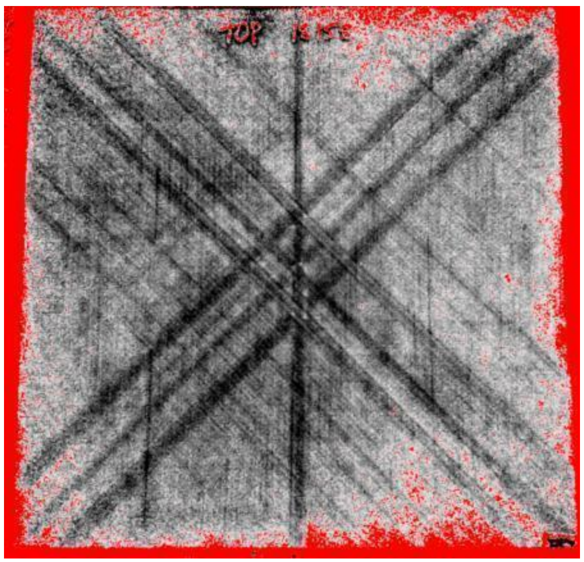
SN 18157 1d 0.42s



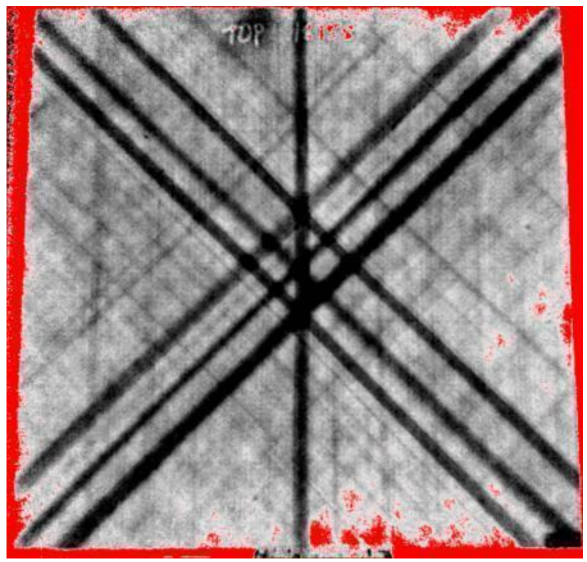
SN 18157 1d 1.0s



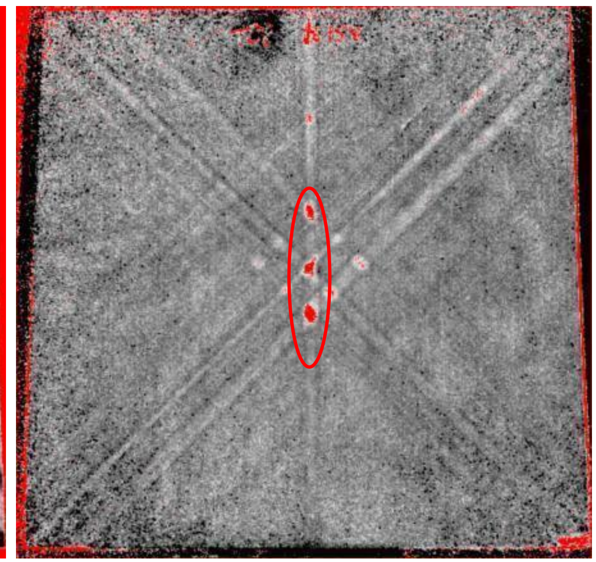
SN 18157 2d PA



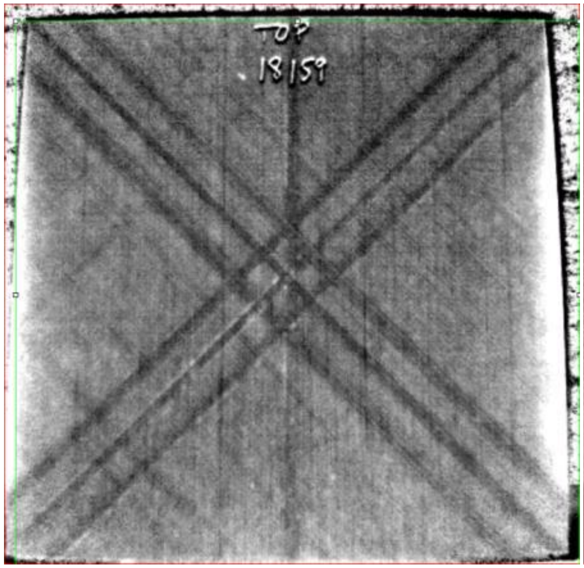
SN 18158 1d 0.42s



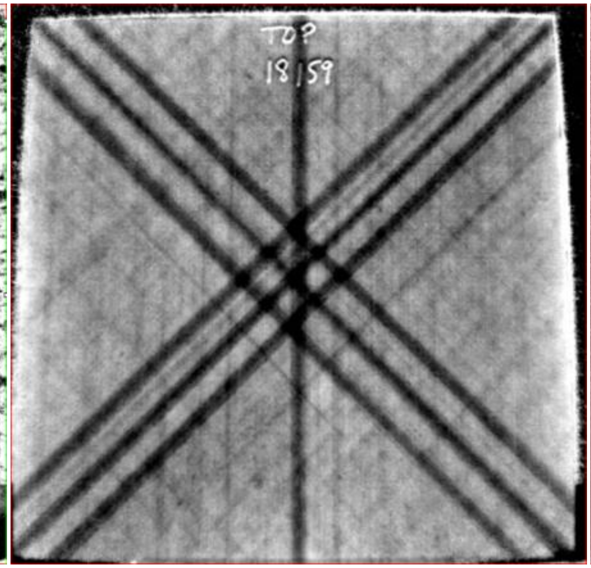
SN 18158 1d 1.0s



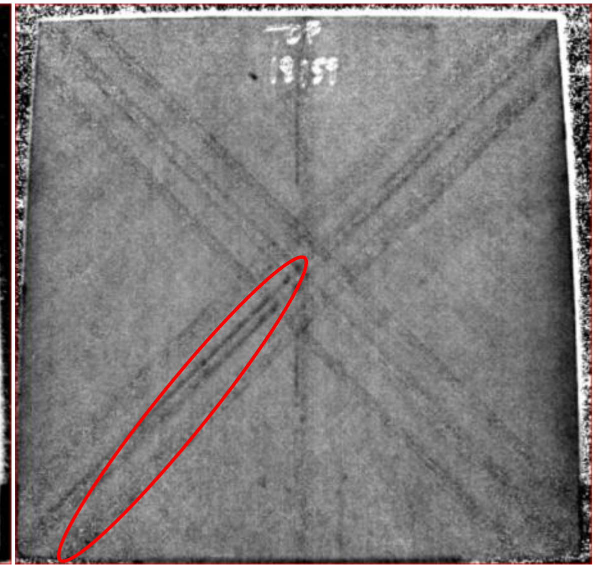
SN 18158 2d PA



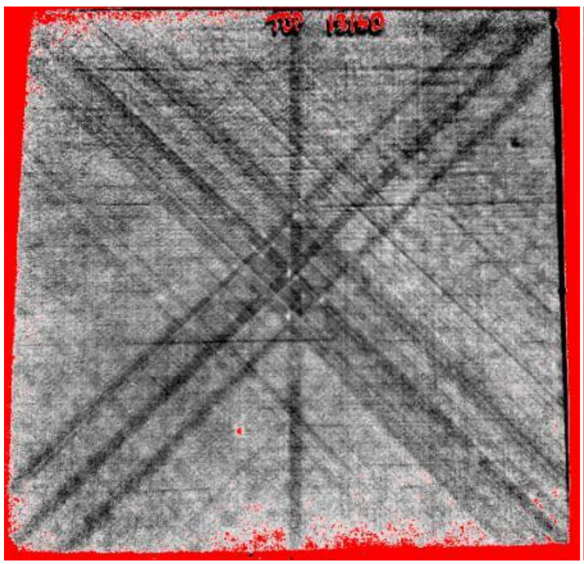
SN 18159 1d 0.42s



SN 18159 1d 1.0s



SN 18159 2d PA



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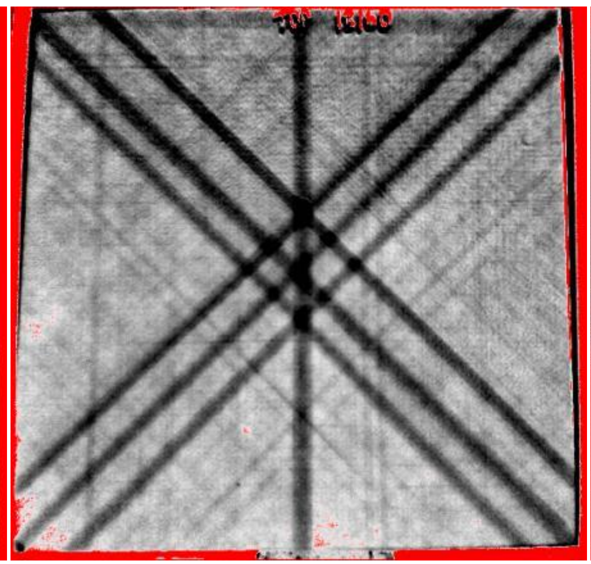

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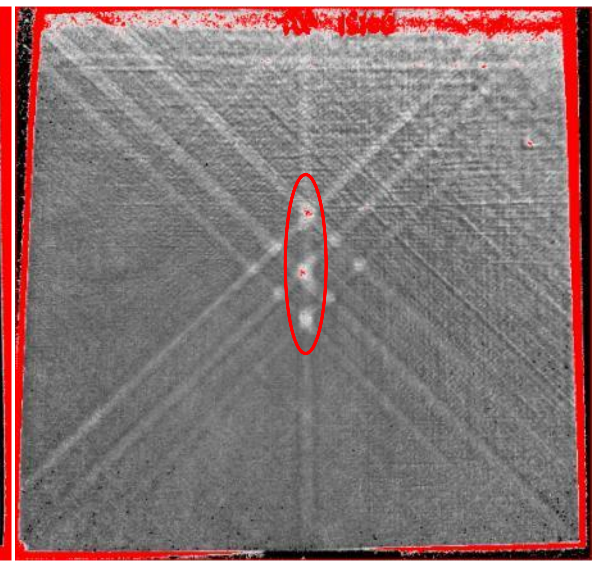
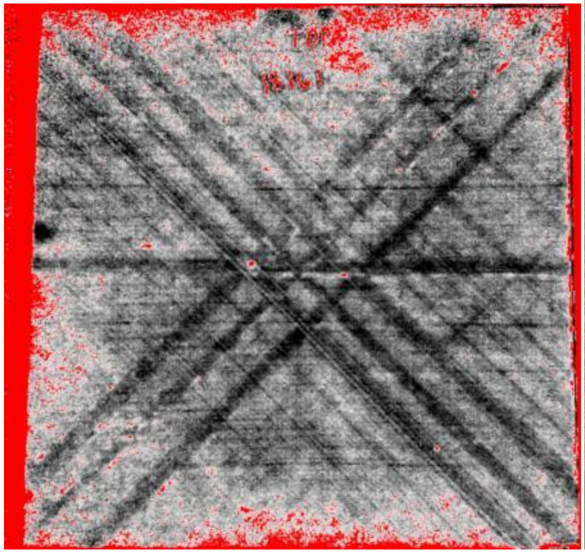
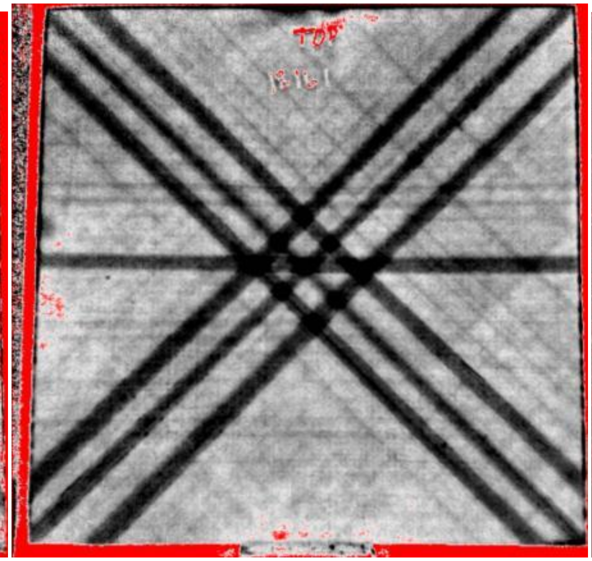


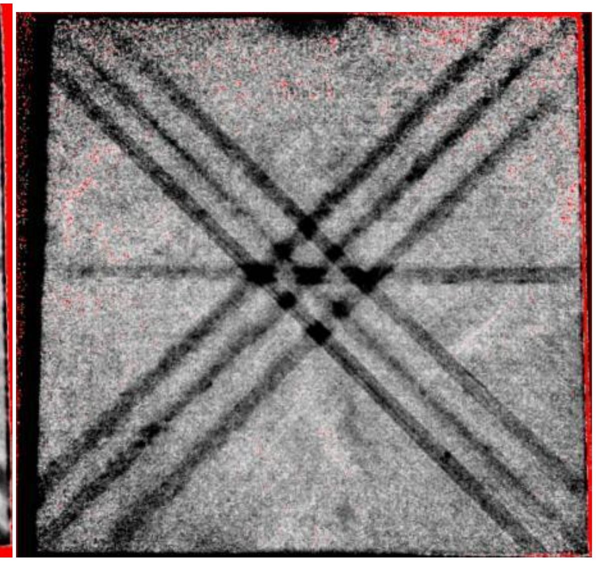
SN18160 2d PA



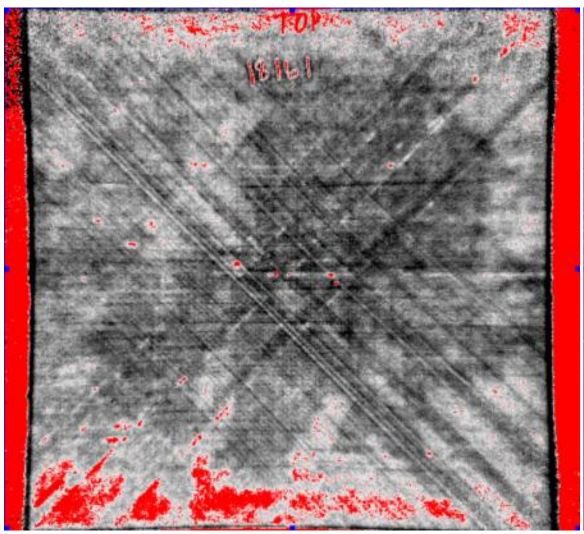
Sn18161 1d 0.42s bag side



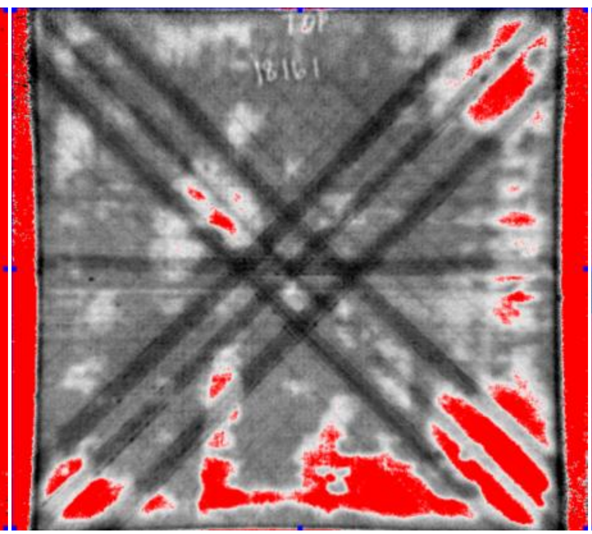
Sn18161 1d 1.0s bag side



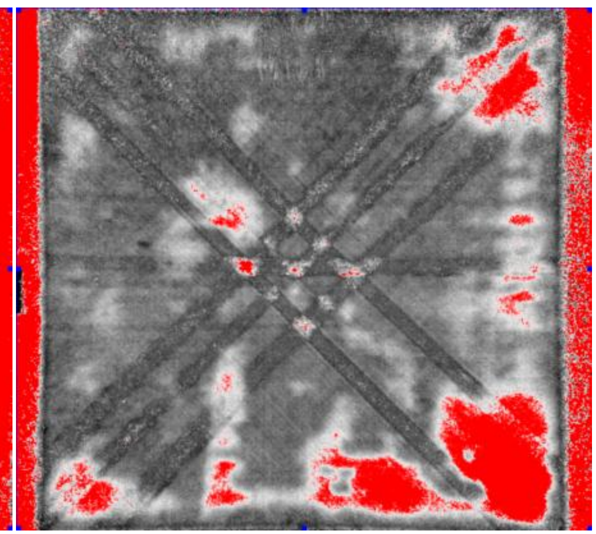
Sn18161 2d PA bag side



SN 18161 1d 0.42s Post strike

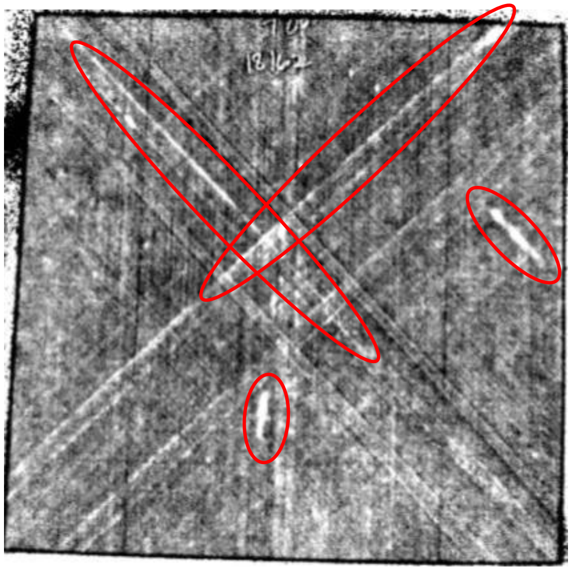


SN 18161 1d 1.0s post strike

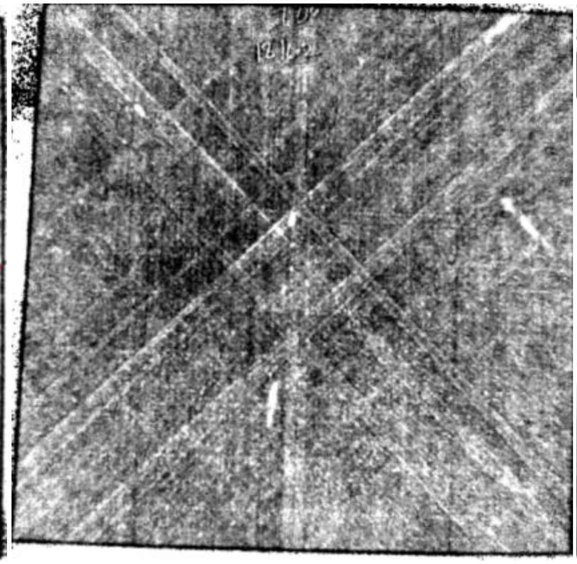


SN 18161 2d PA Post strike

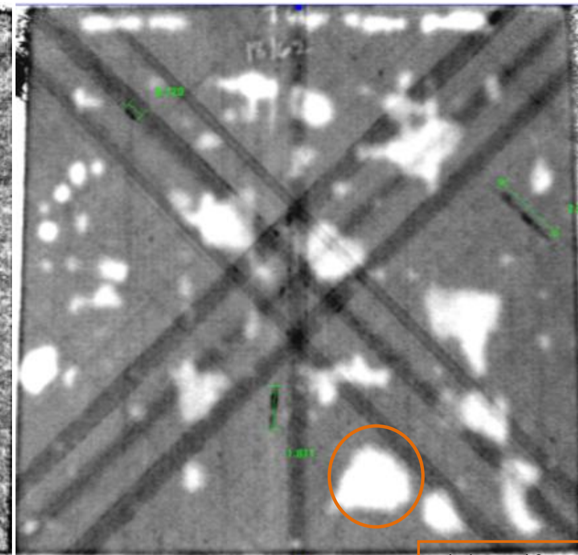
Light artifacts from backside adhesive bond variation



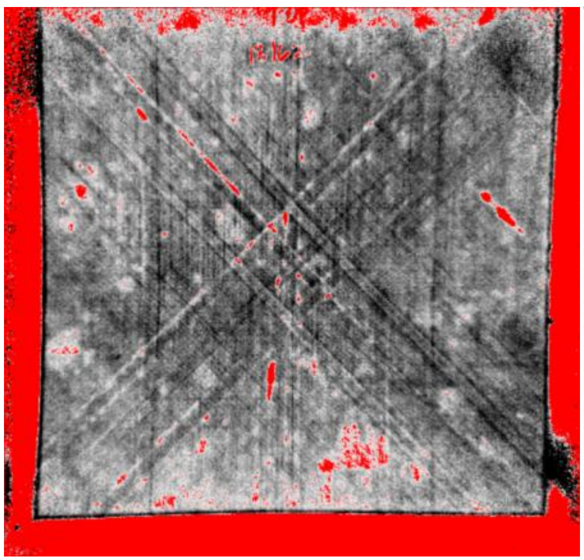
SN 18162 1d 0.3s assembled



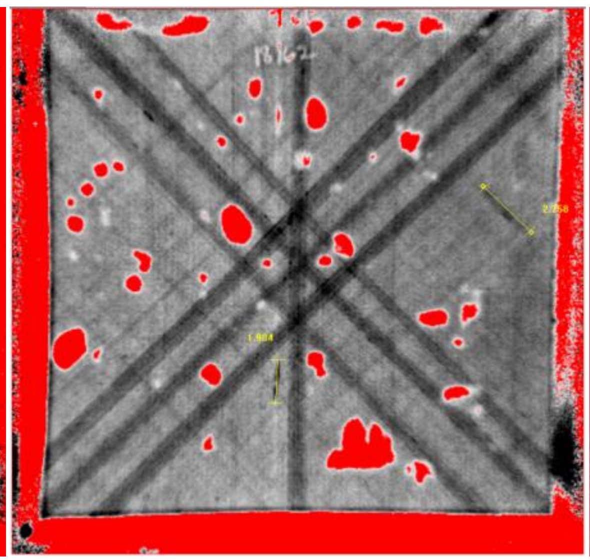
SN 18162 1d 0.18s assembled



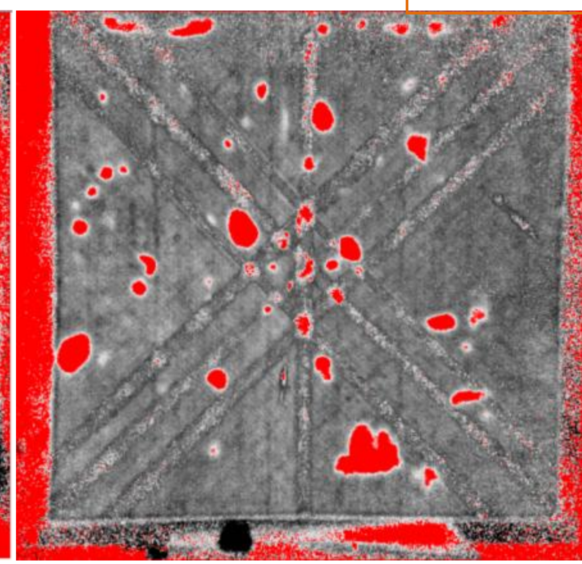
SN 18162 1d 1.72s assembled



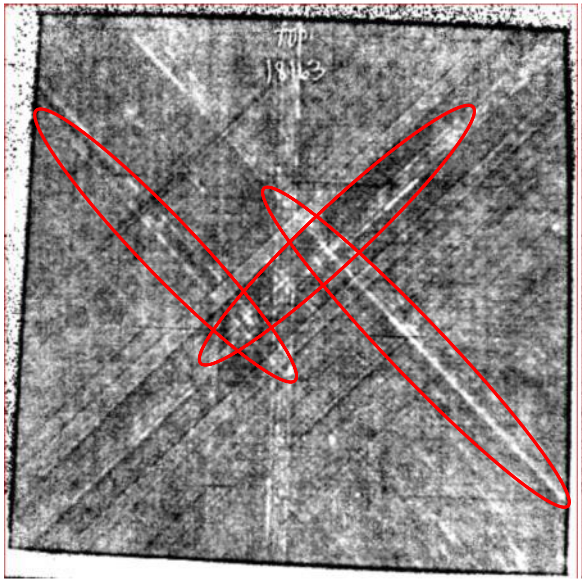
SN 18162 1d 0.42s Post strike

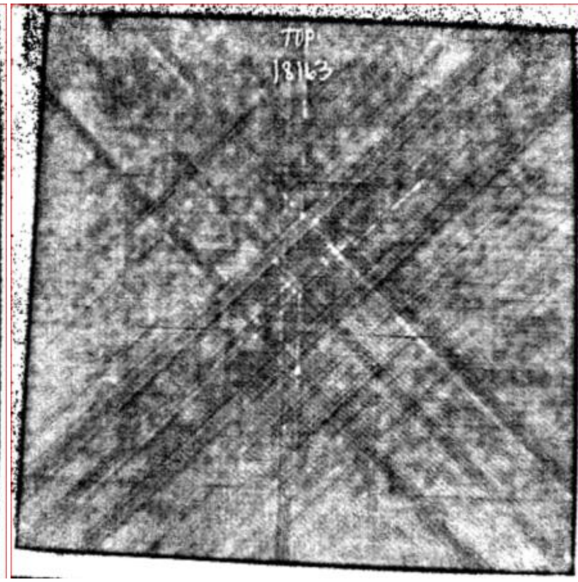


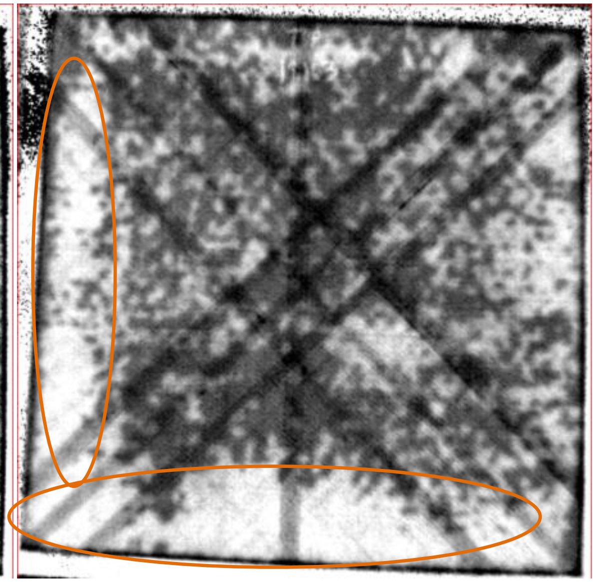
SN 18162 1d 1.0s post strike



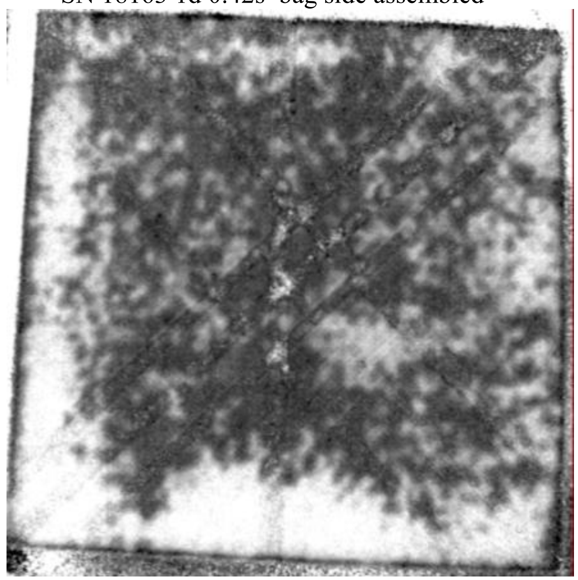
SN 18162 2d PA Post strike

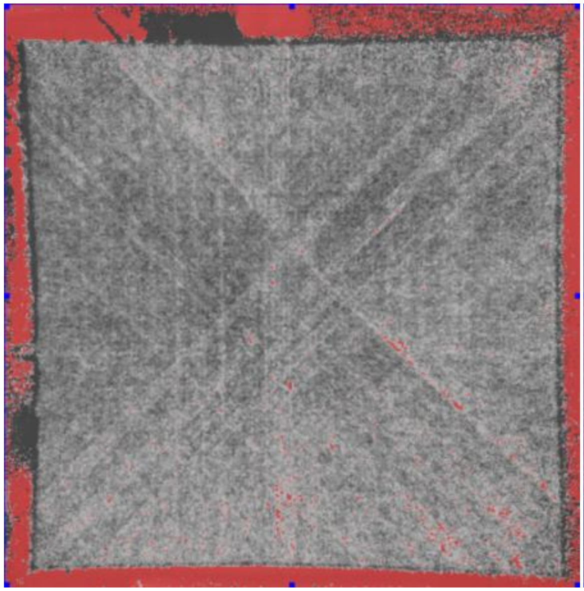

SN 18163 1d 0.3s bag side assembled


SN 18163 1d 0.42s bag side assembled

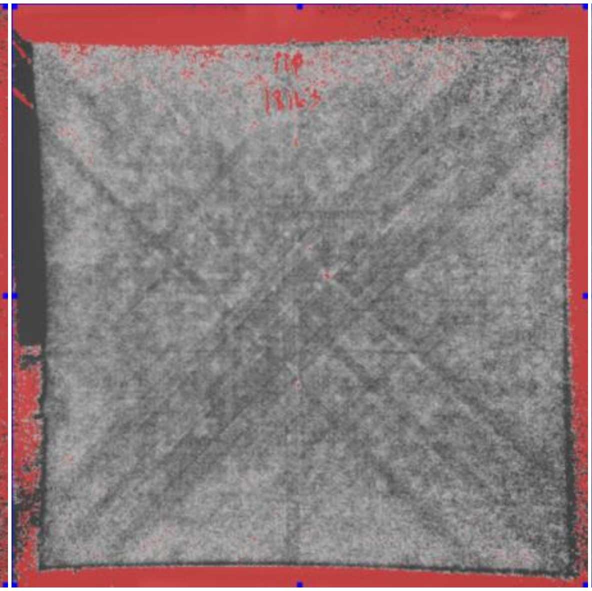

SN 18163 1d 1.0s bag side assembled

Light artifacts from backside adhesive bond variation

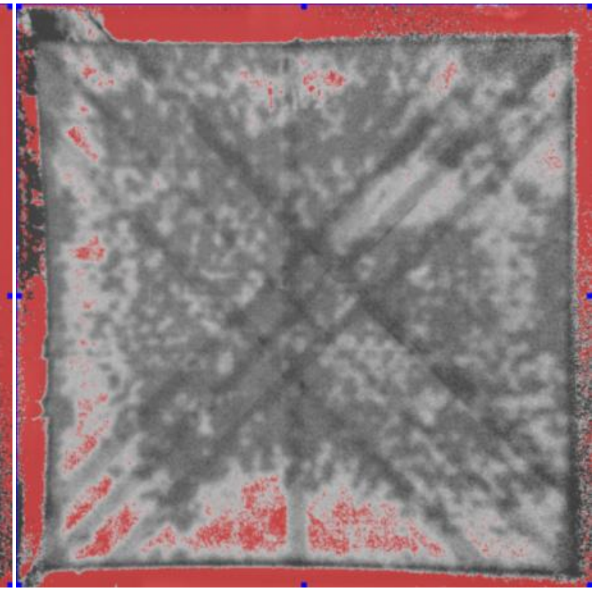

SN 18163 2d PA bag side assembled



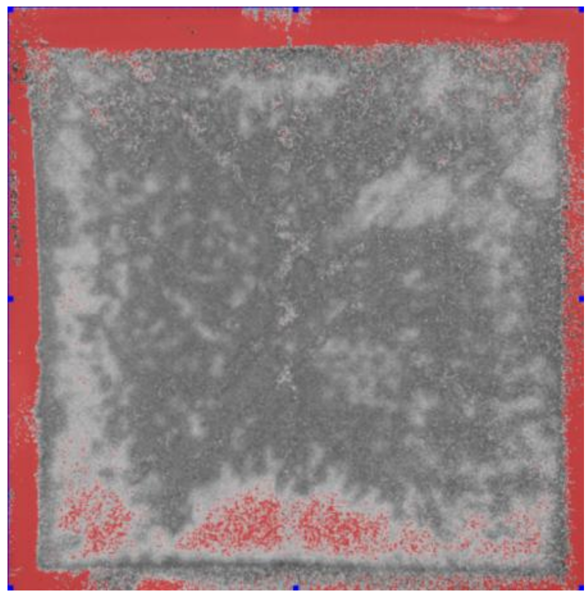
SN 18163 1d 0.16s post strike



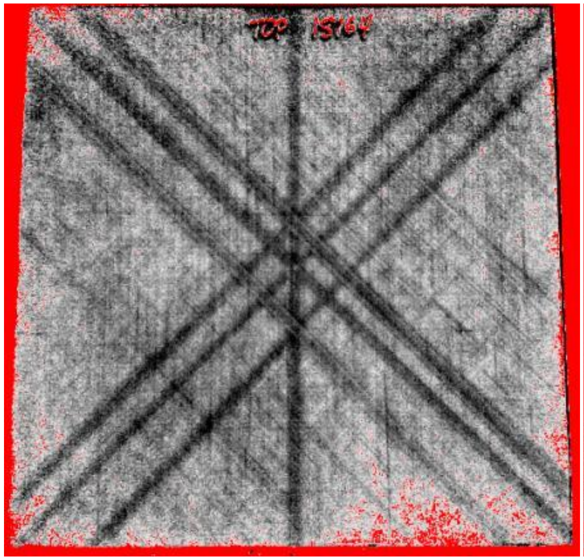
SN 18163 1d 0.42s post strike



SN 18163 1d 1.0s post strike



SN 18163 2d PA post strike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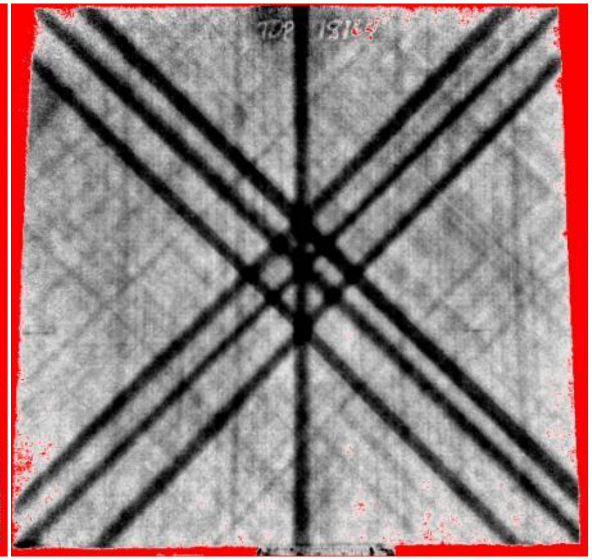
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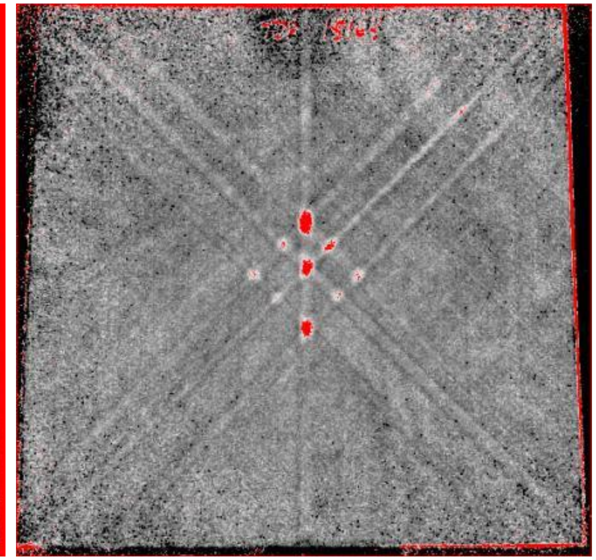
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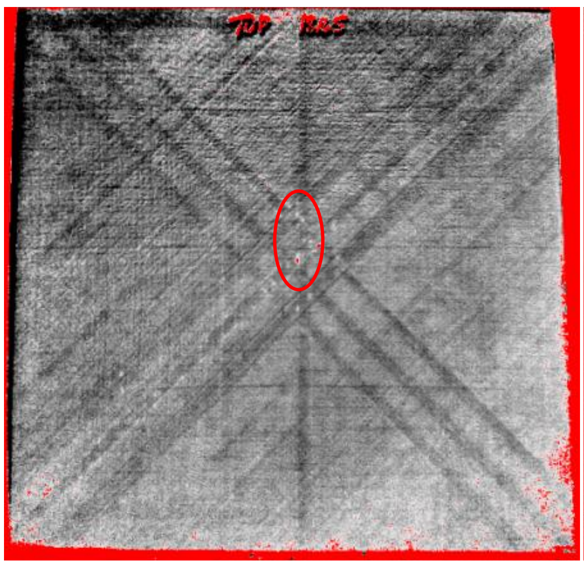
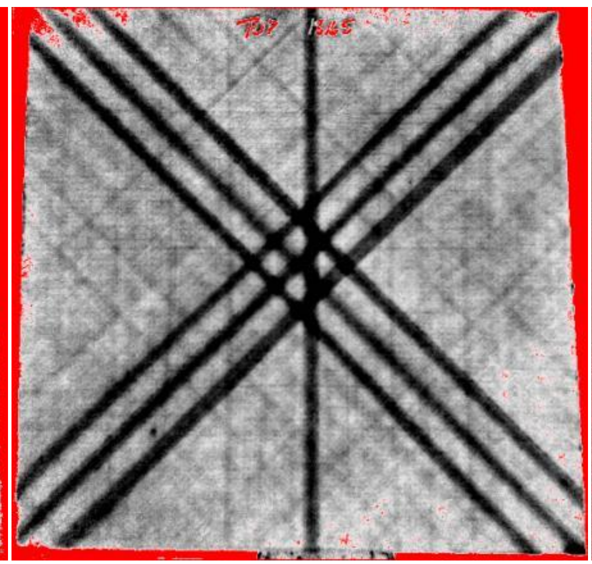
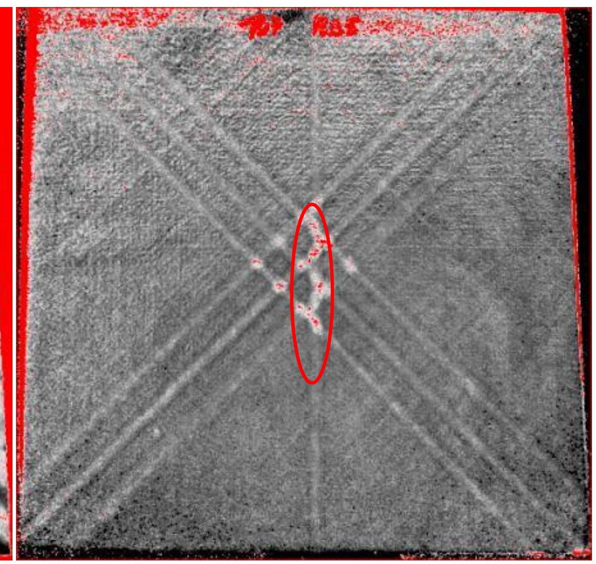
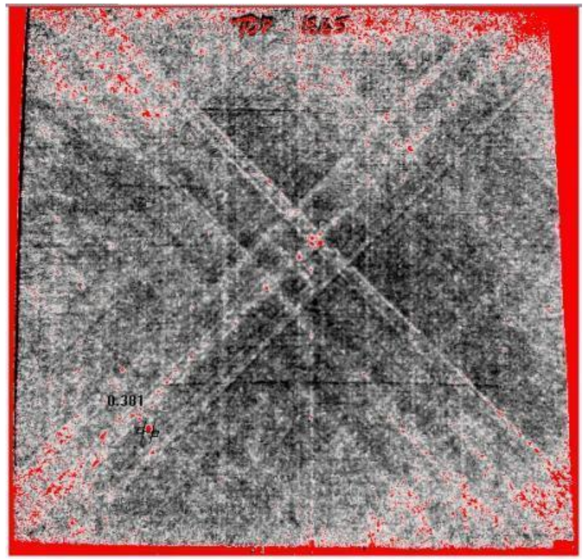
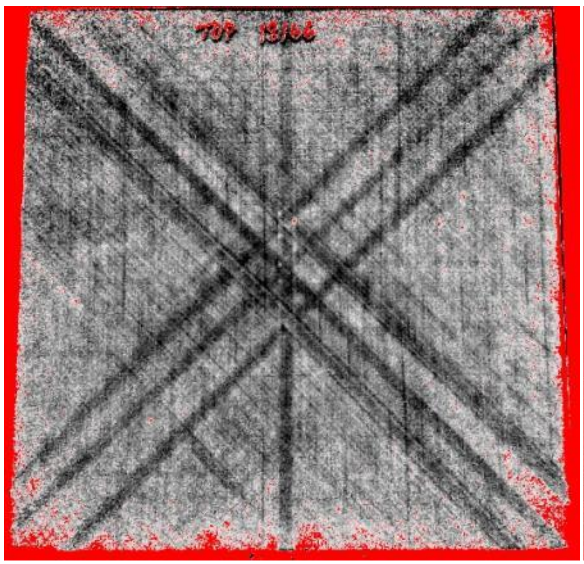

SN 18165 1d 0.42s


SN 18165 1d 1.0s

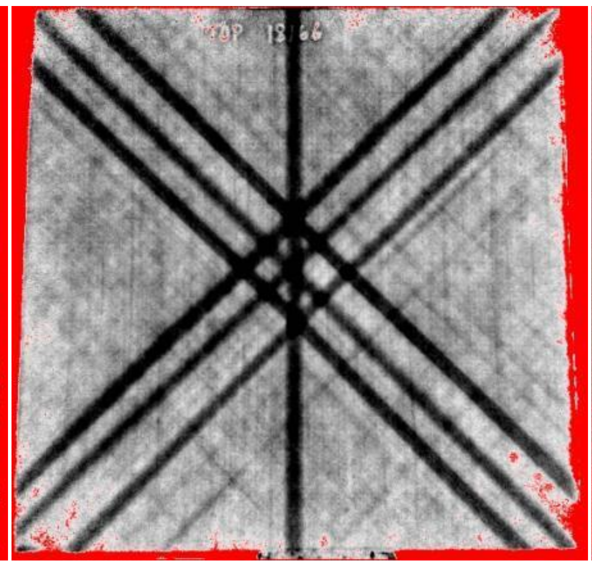

SN 18165 2d PA



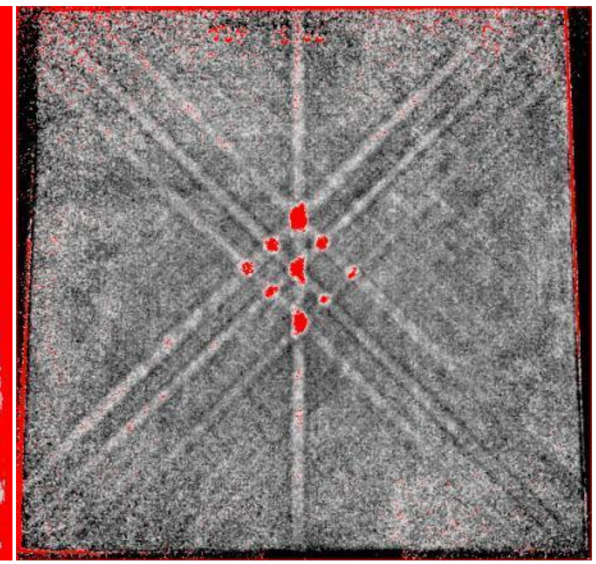
SN 18165 1d 0.3s void 0.38 in



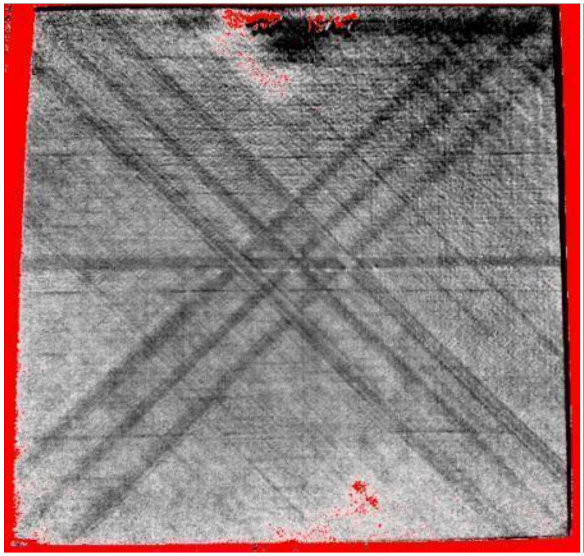
SN 18166 1d 0.42s



SN 18166 1d 1.0s



SN 18166 2d PA



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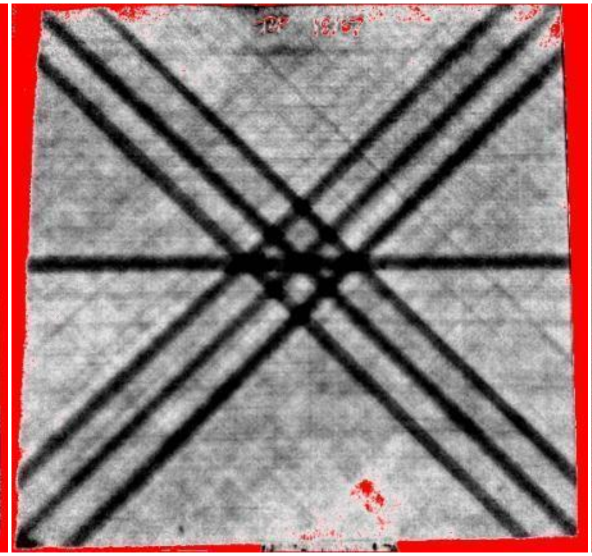

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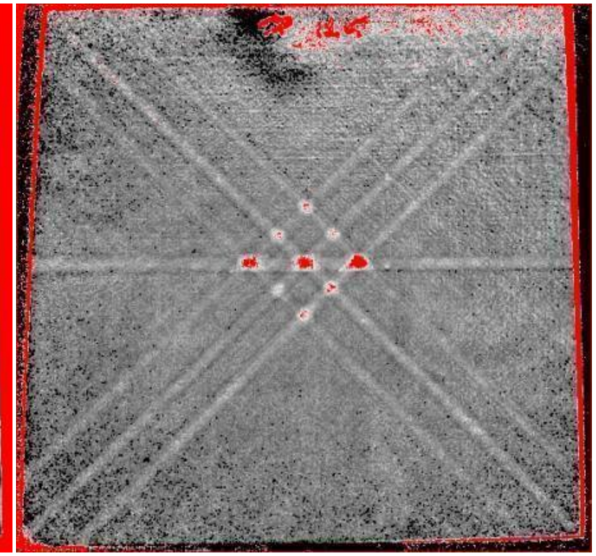
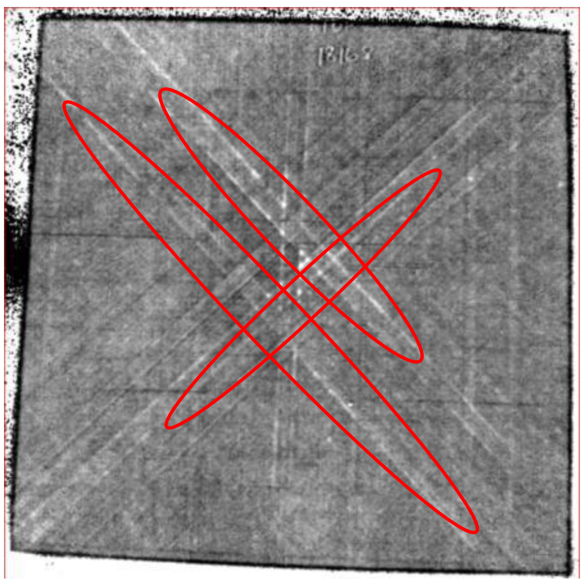
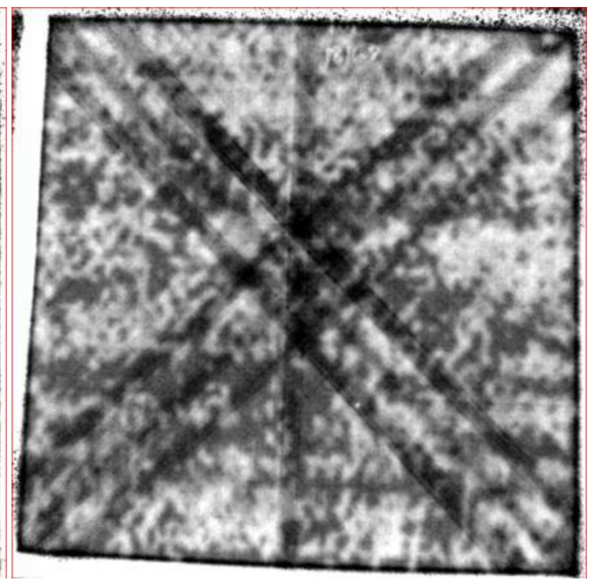


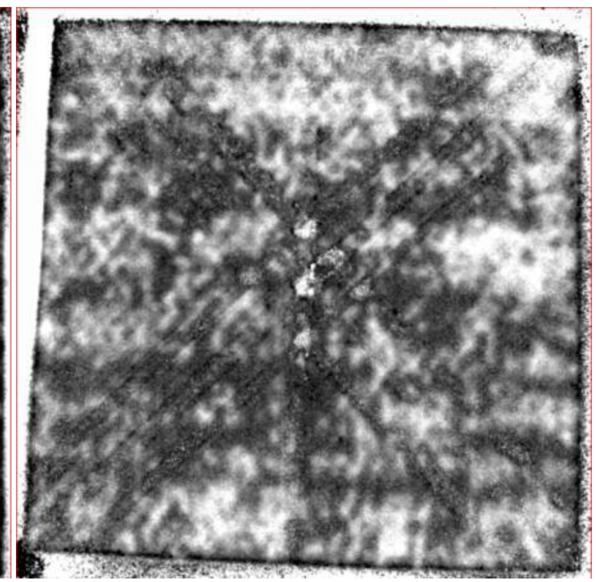
SN 18167 2d PA



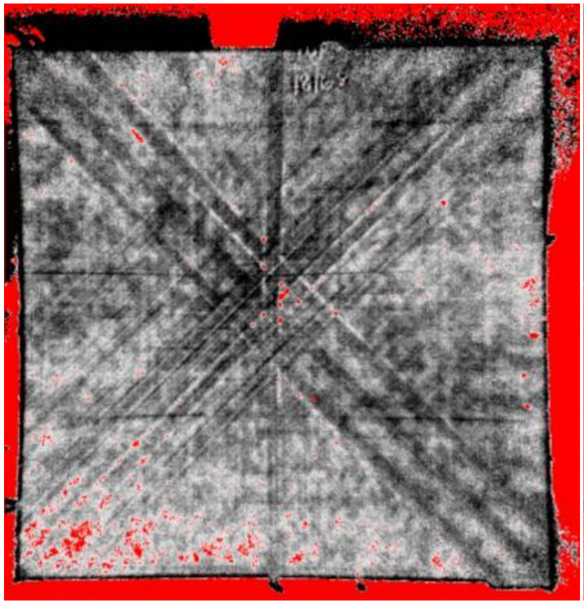
SN18168 1d 0.42s assembled



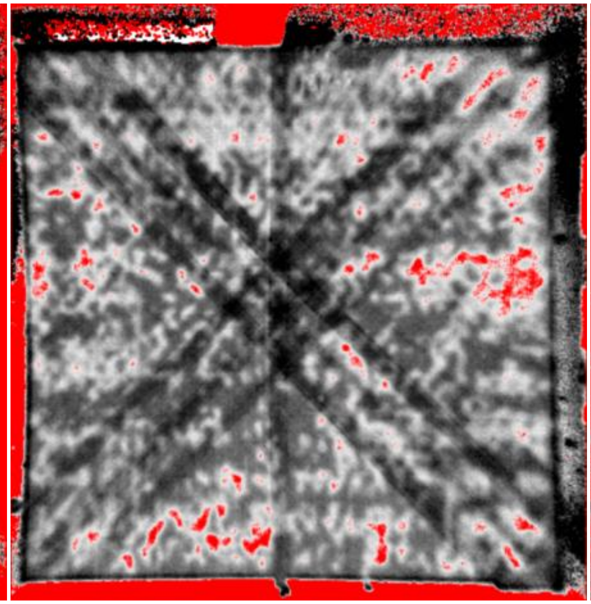
SN18168 1d 1.0s assembled



SN18168 2d PA assembled



SN 18168 1d 0.42s post strike



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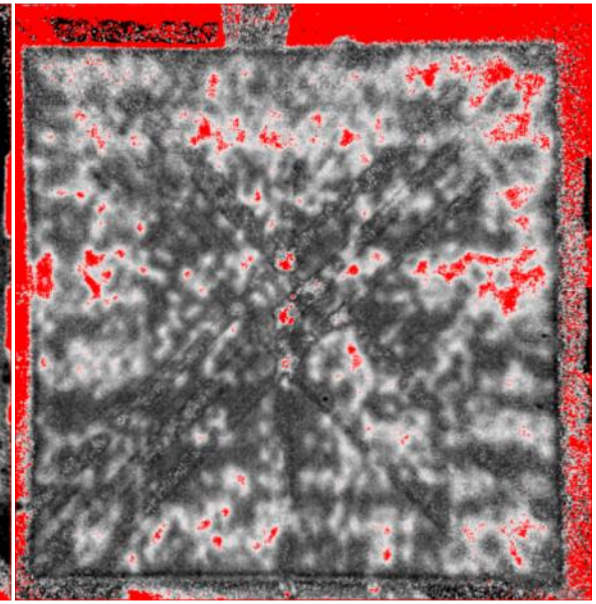

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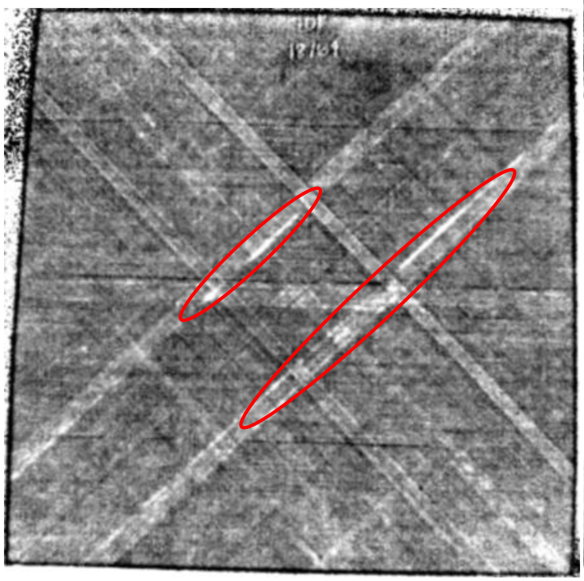

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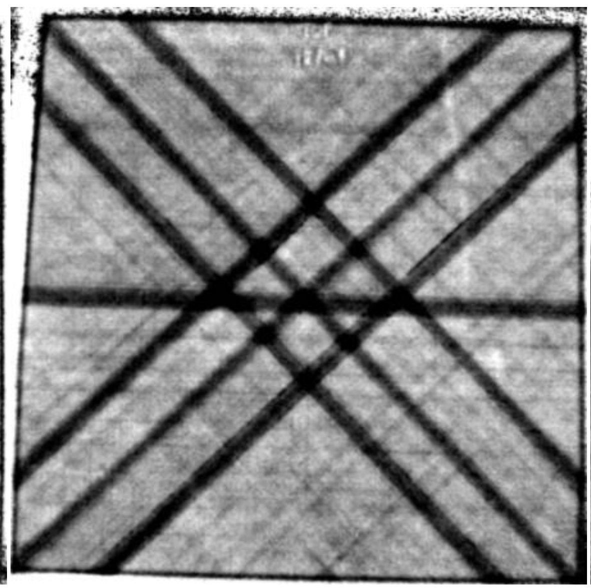

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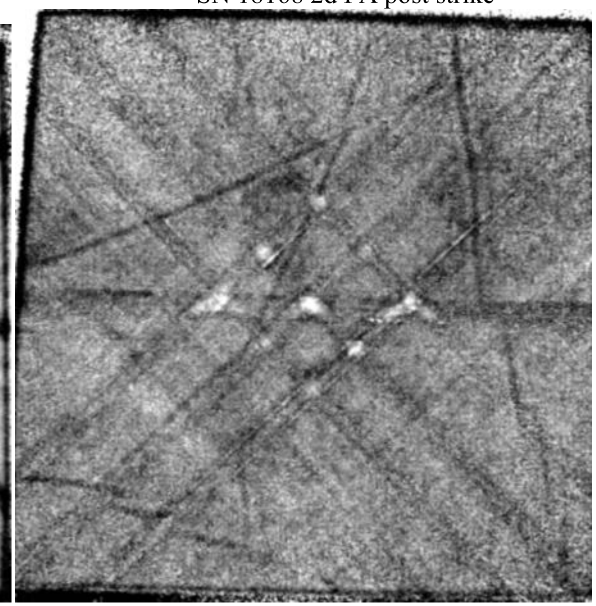

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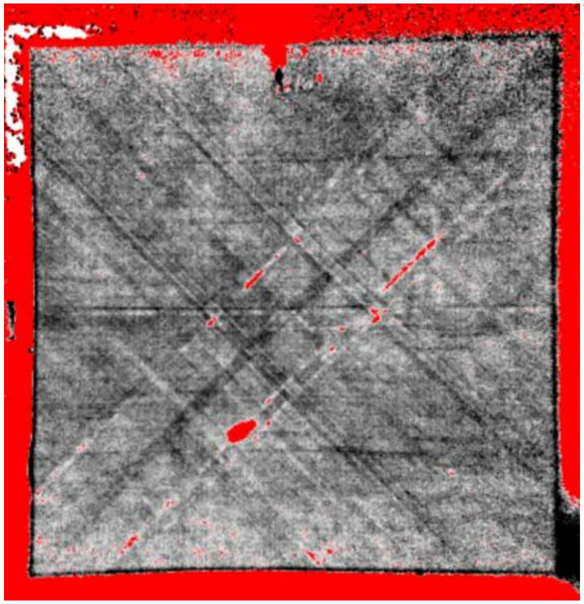

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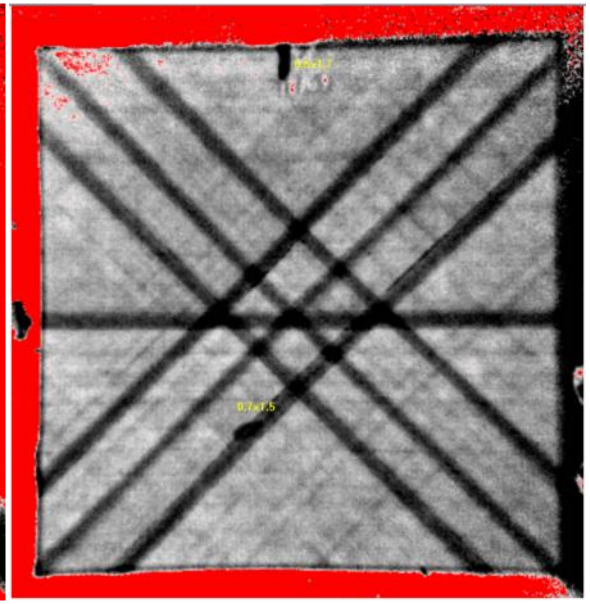
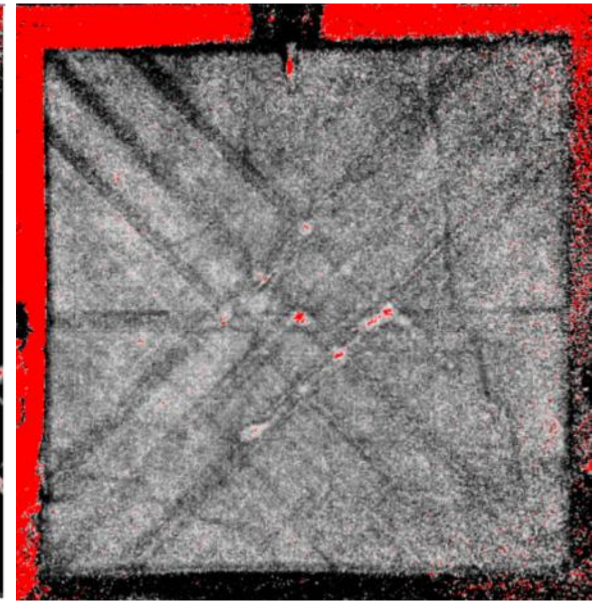


SN 18169 1d 1.0s voids post strike



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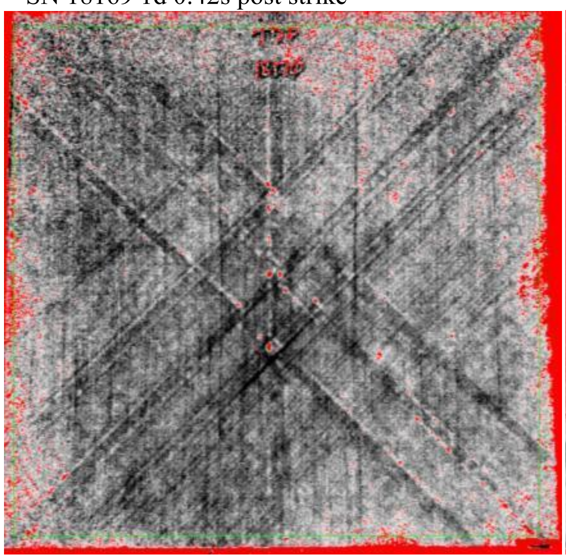

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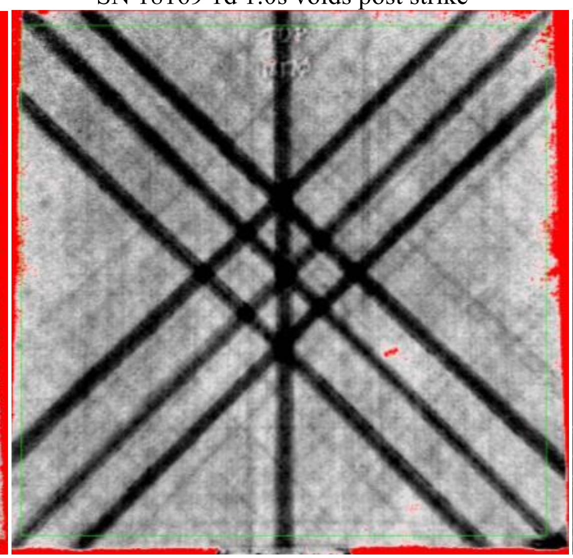

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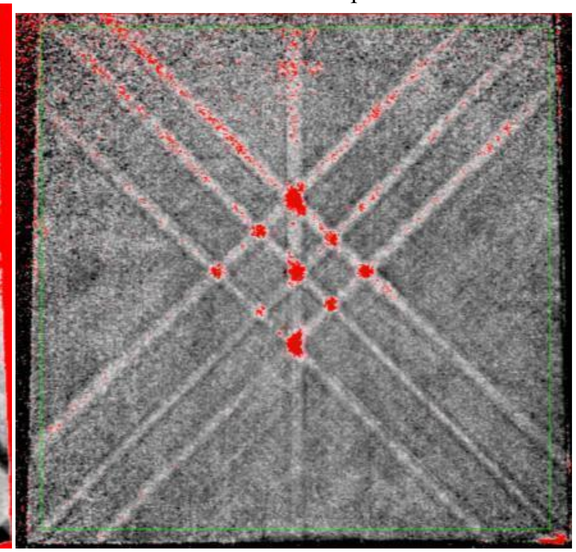

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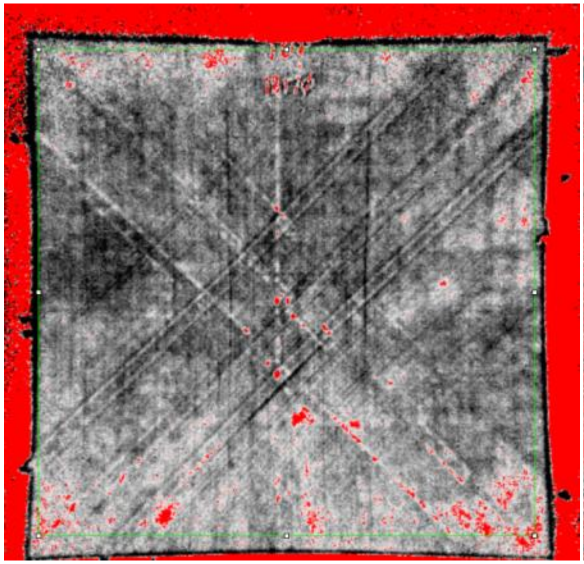
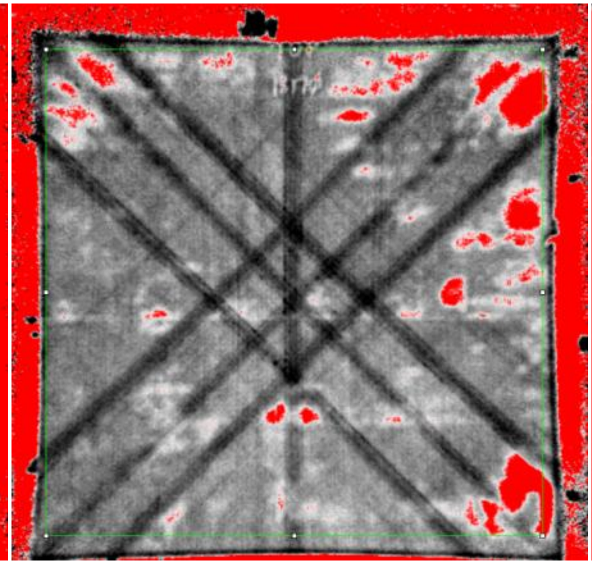


SN 18170 1d 0.42s post strike



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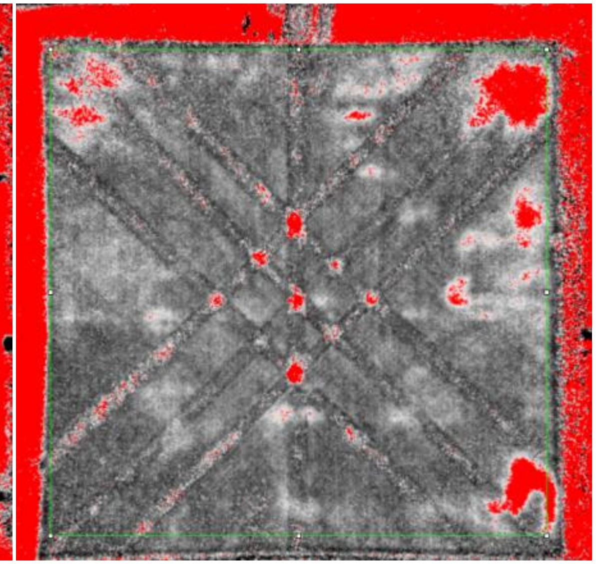

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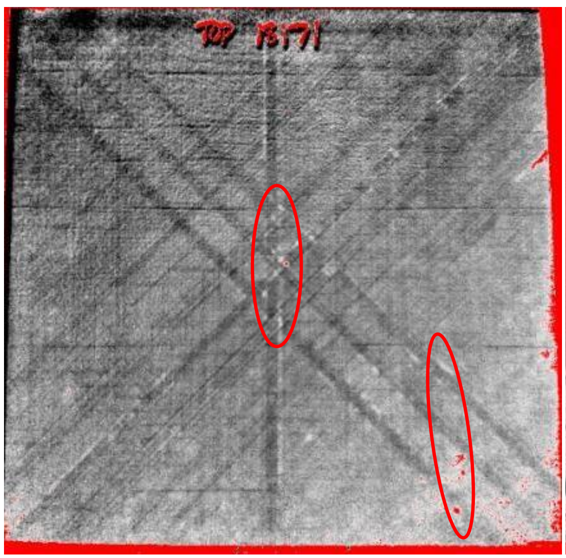
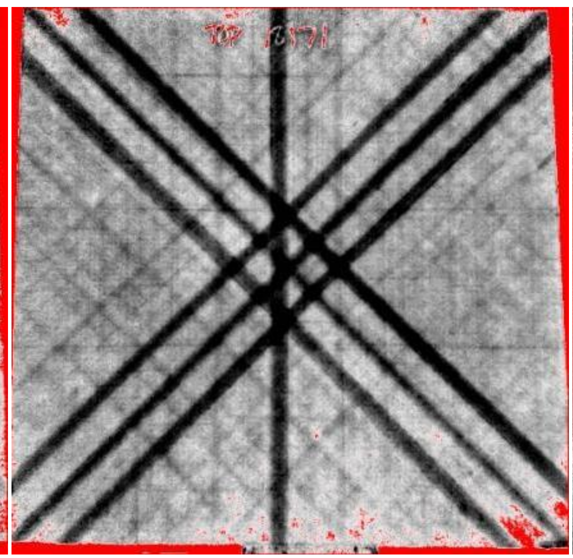


SN18171 1d 0.42s



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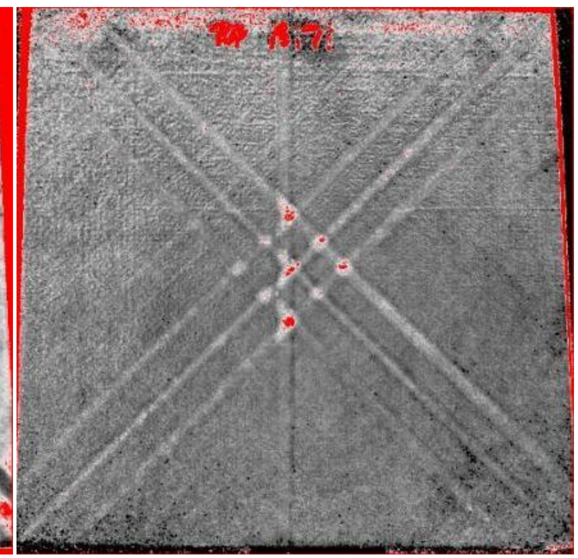
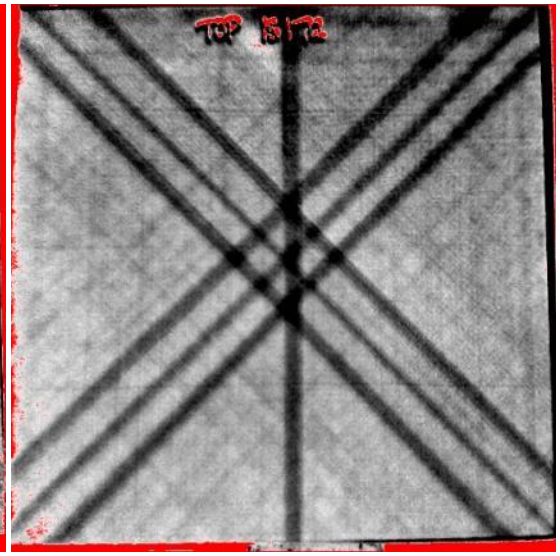


SN 18171 2d PA


SN 18172 1d 0.42s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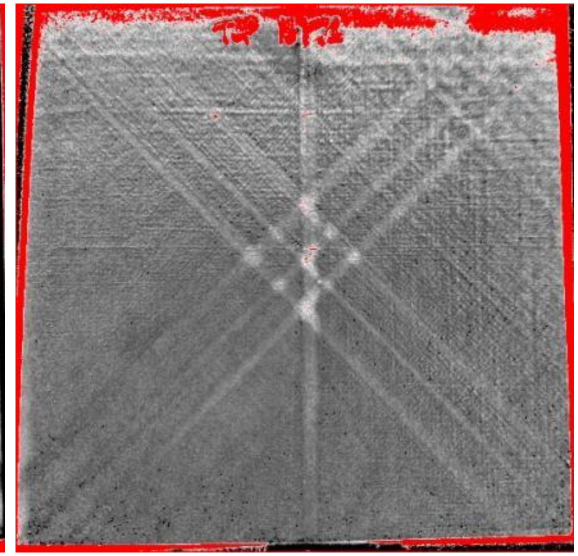
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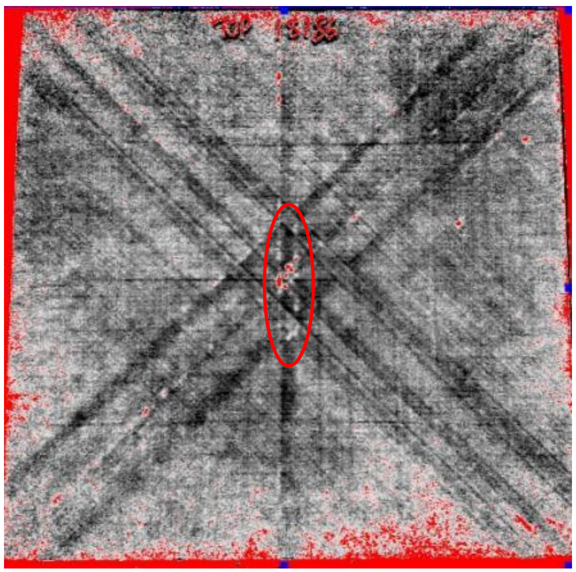
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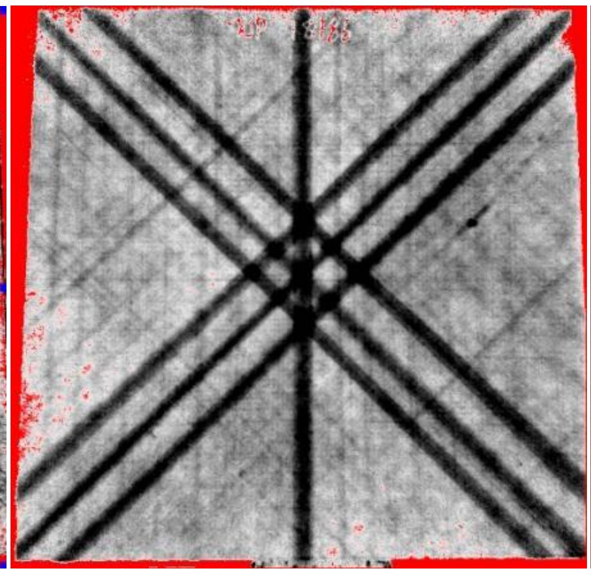
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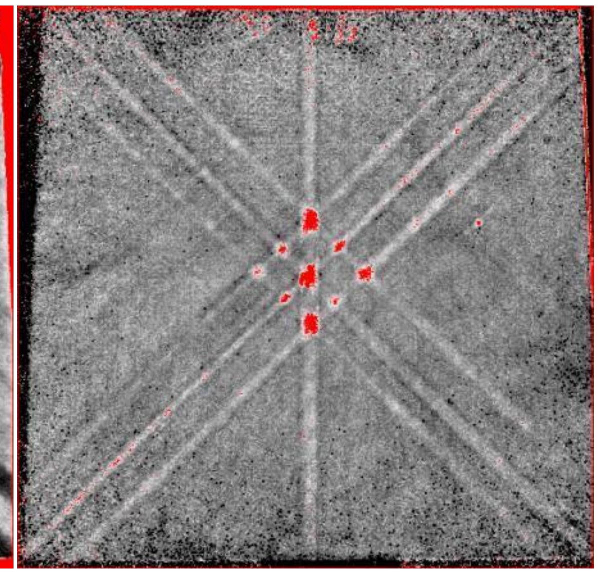
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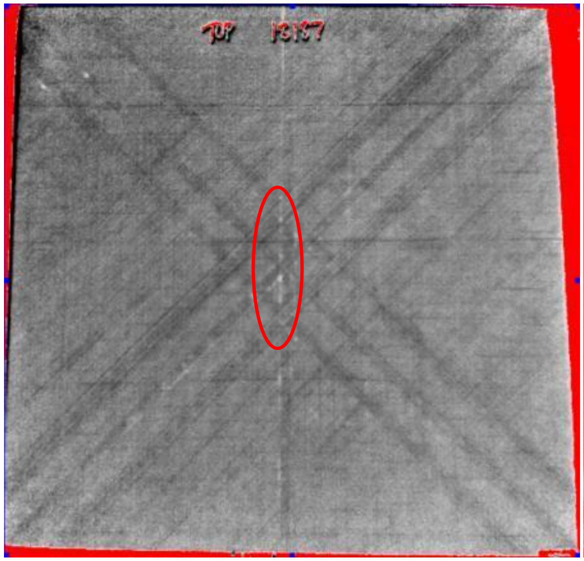
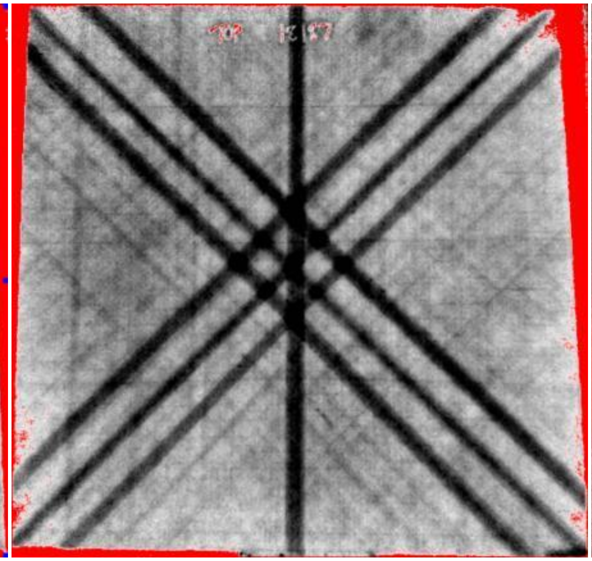
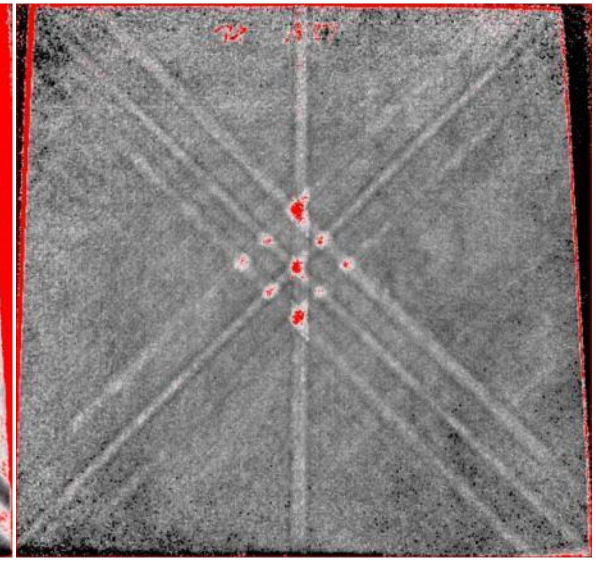


SN18187 1d 0.42s



SN18187 1d 1.0s



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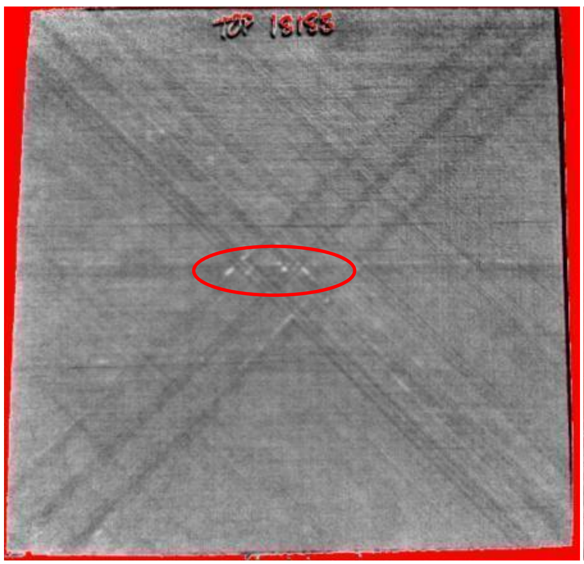

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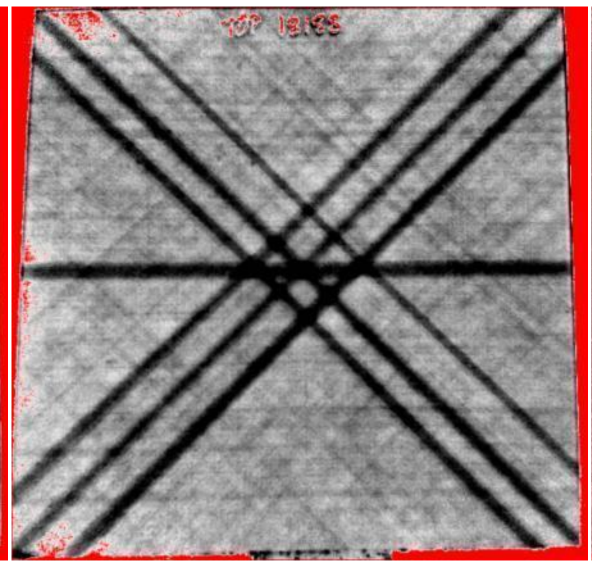

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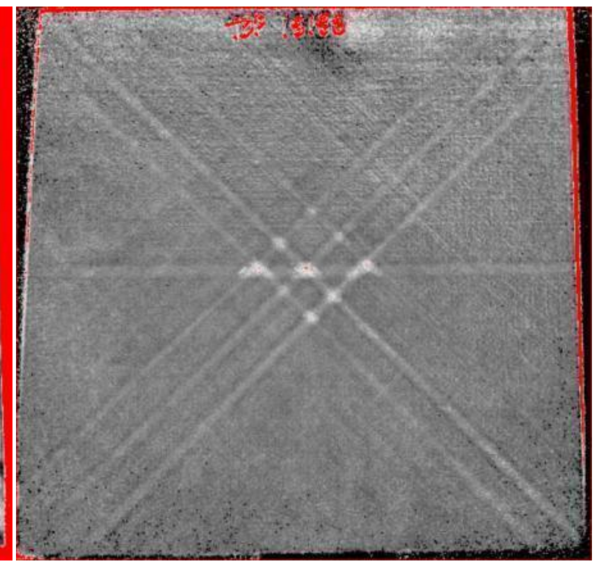

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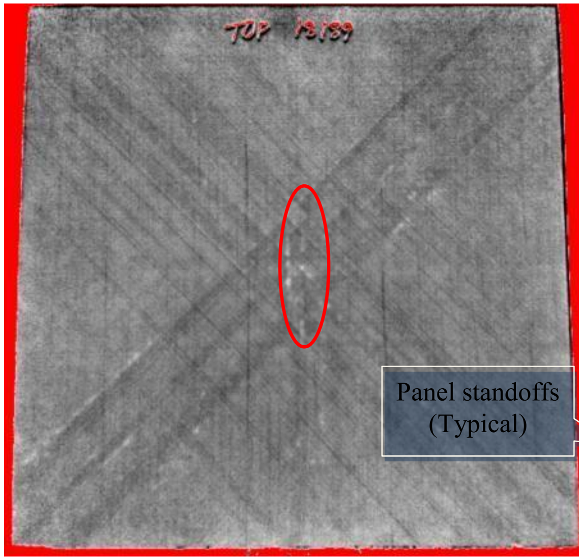
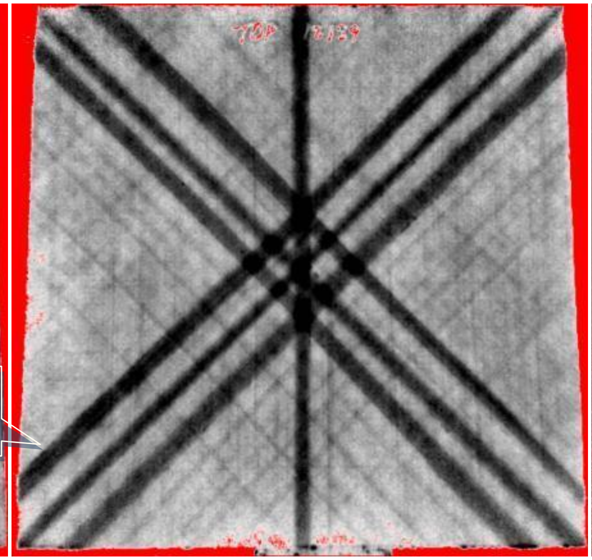


SN18189 1d 0.42s



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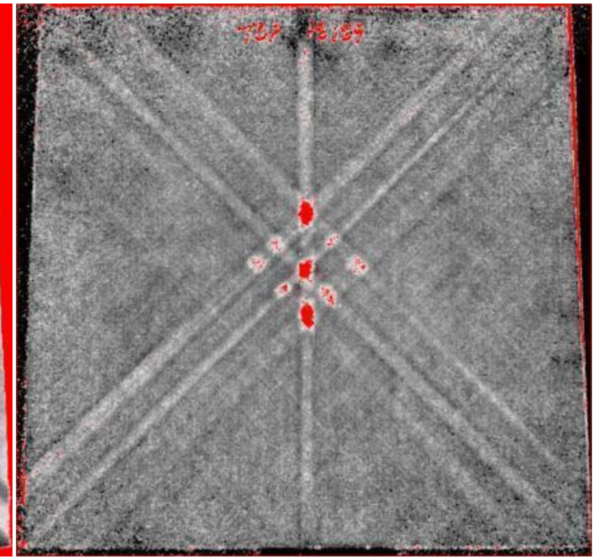

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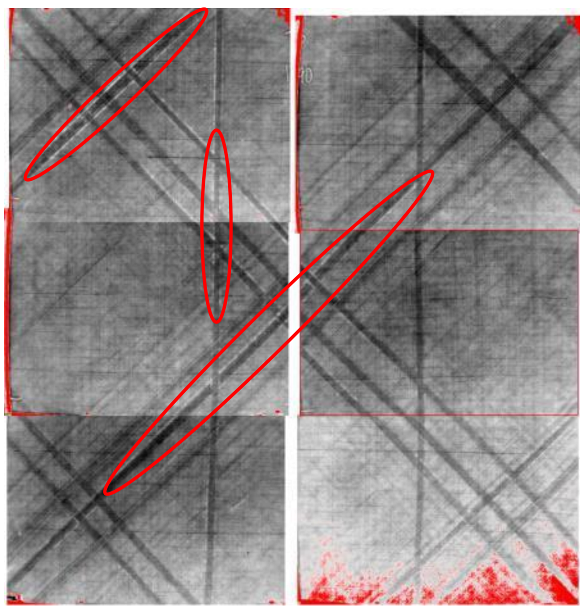

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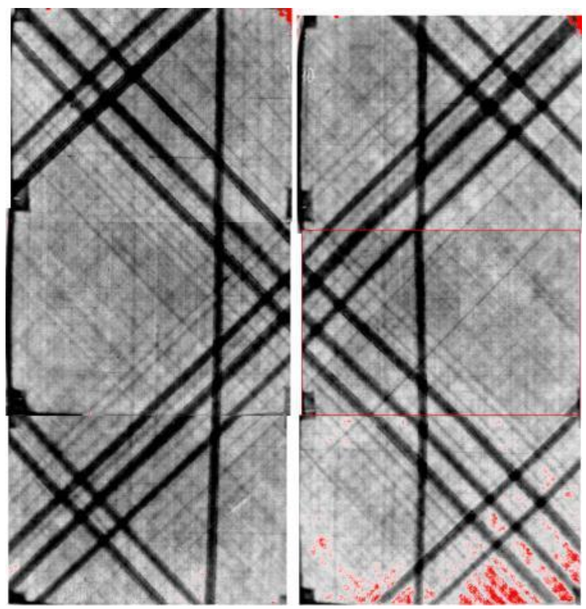

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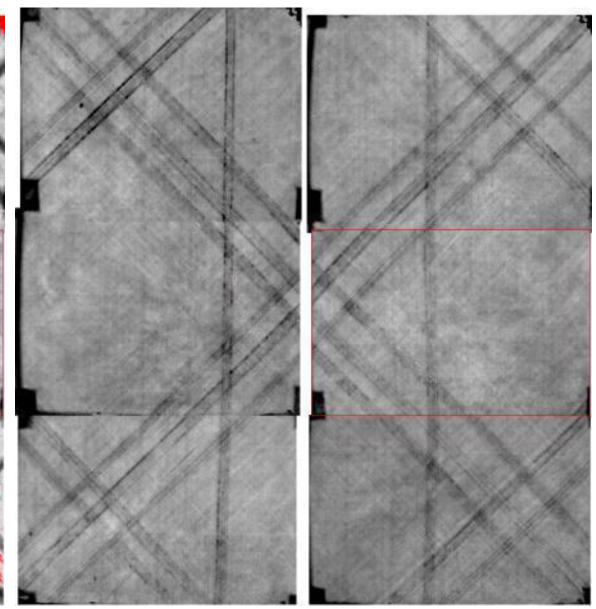

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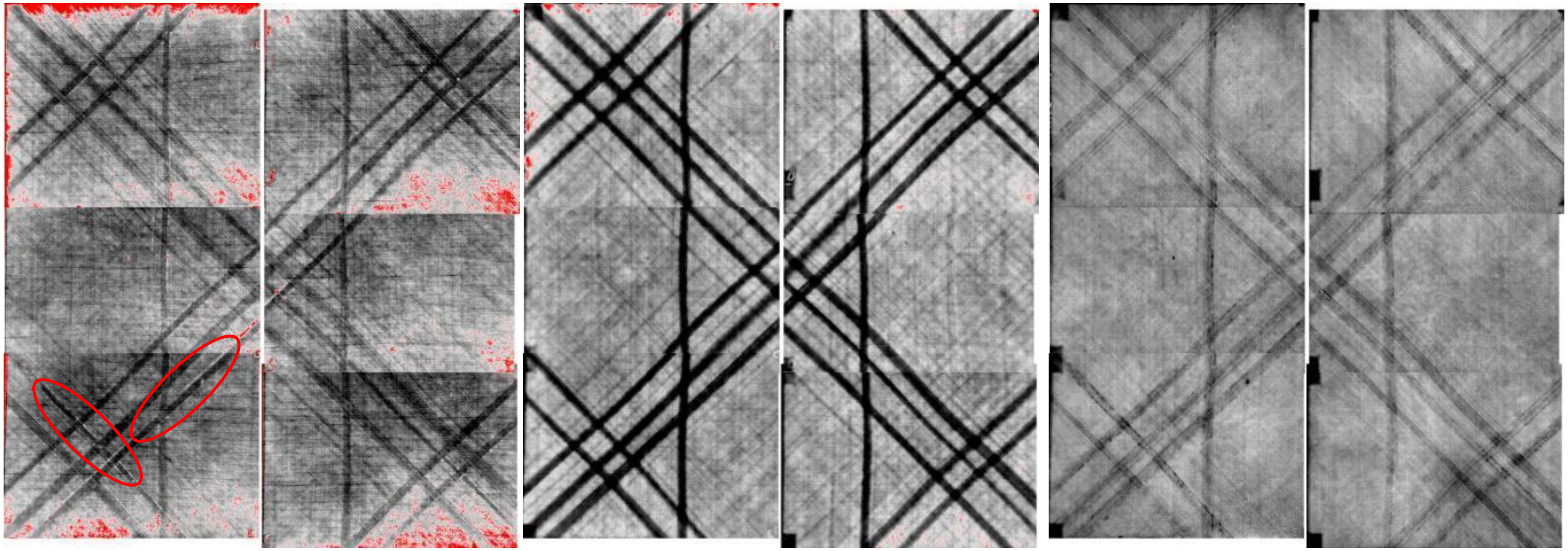
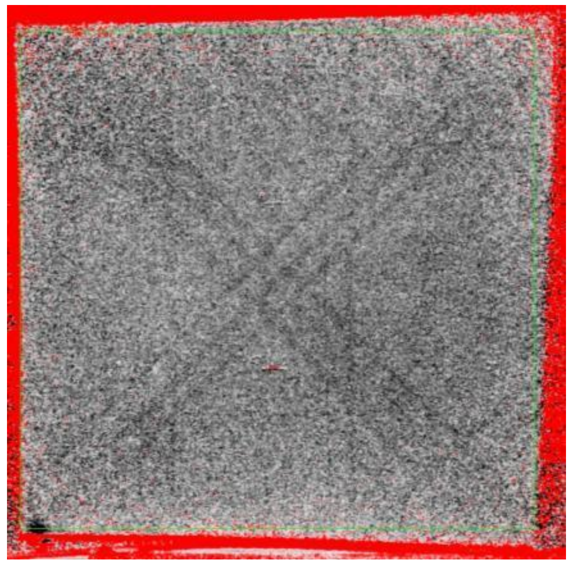
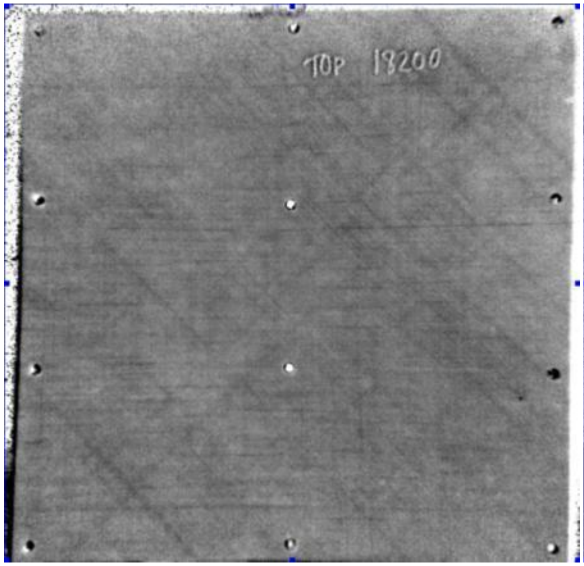


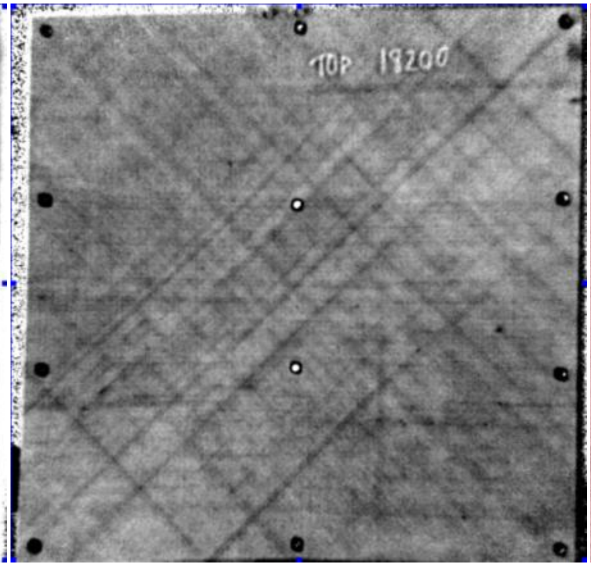
SN18191 1d 0.42s SN18191 1d 1.0s SN18191 2d PA



SN18191 1d 0.42s single shot 48x48 in.



SN 18200 1d 0.3s



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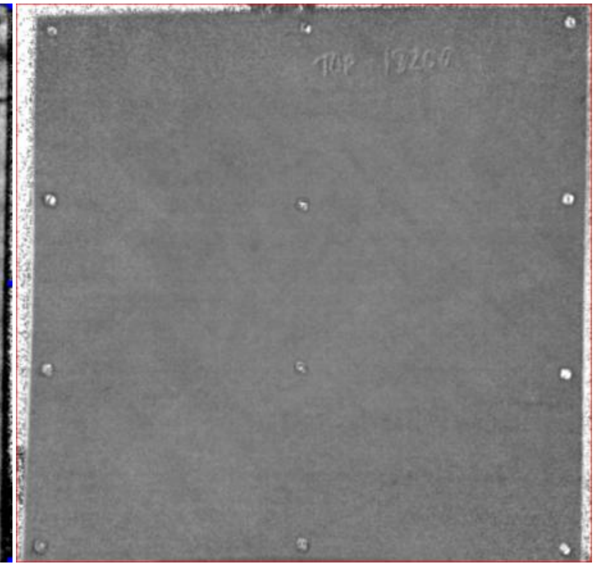

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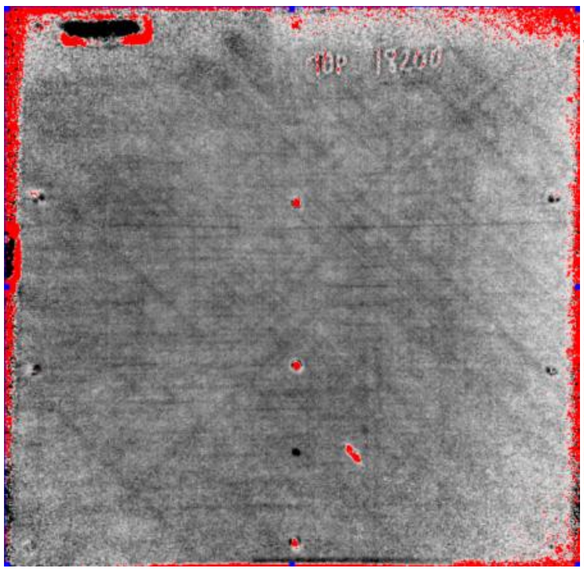
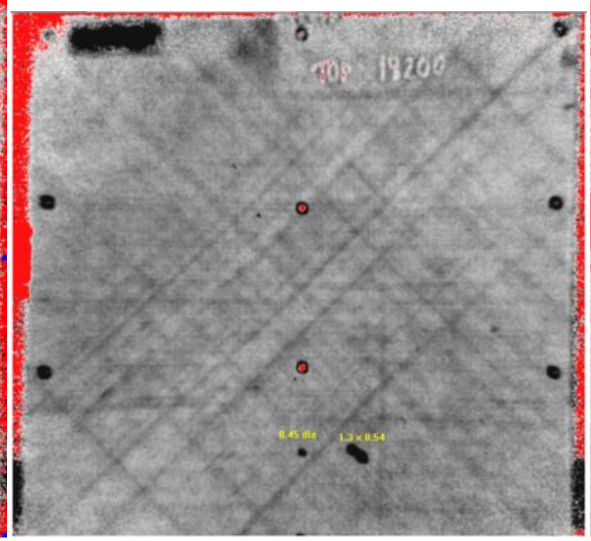
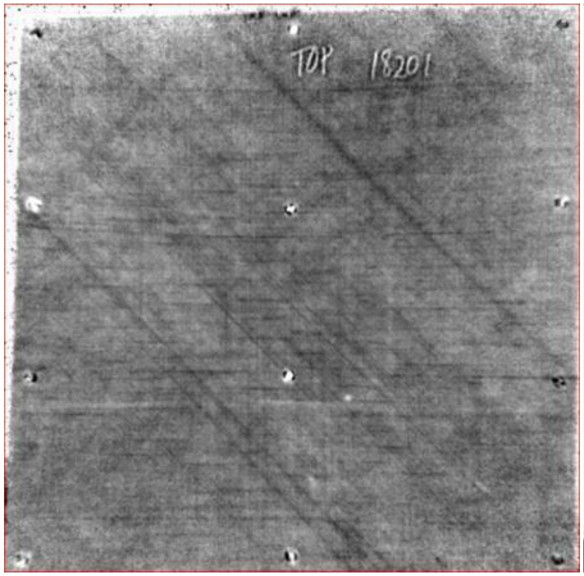


SN 18200 1d 0.42s Post impact



SN 18200 1d 1.0s voids post impact

SN 18200 2d PA post impact



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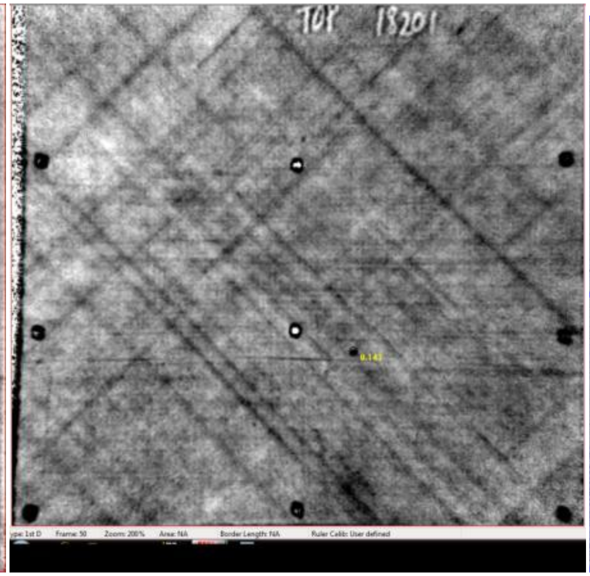
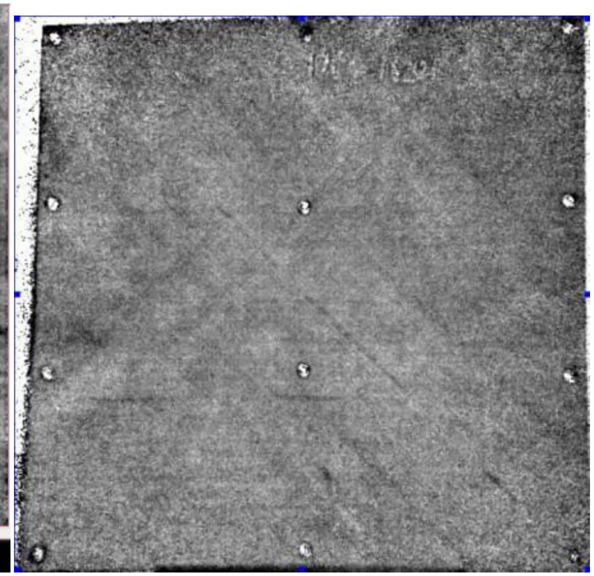
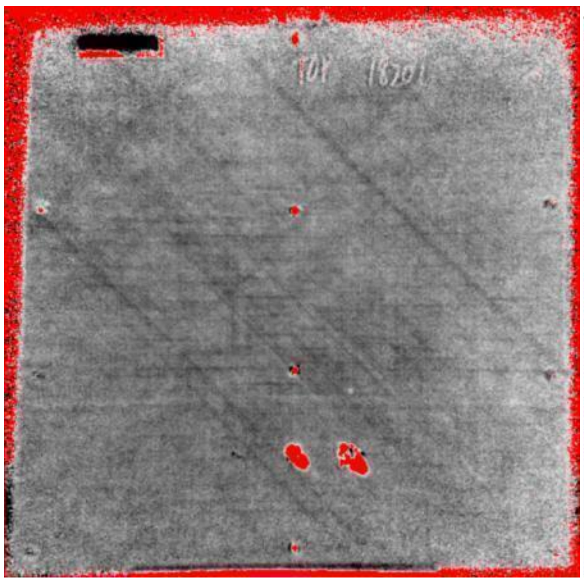


SN 18201 1d 1.0s void


SN 18201 2d PA



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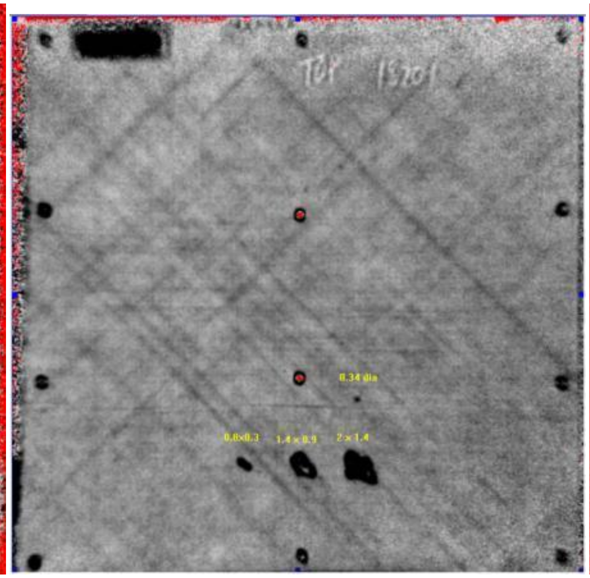

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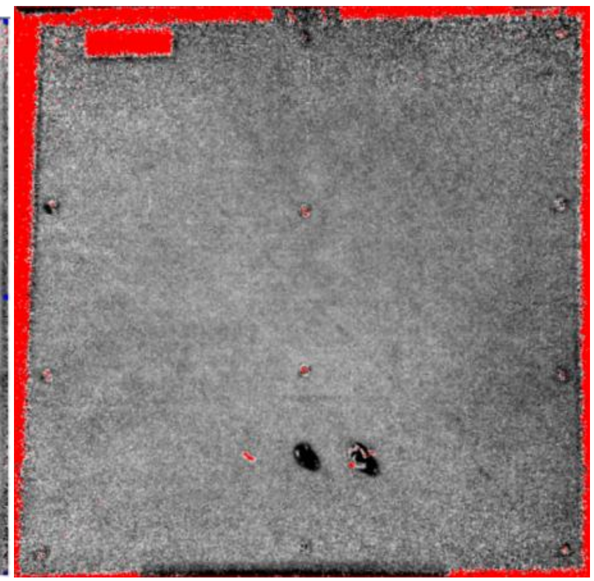
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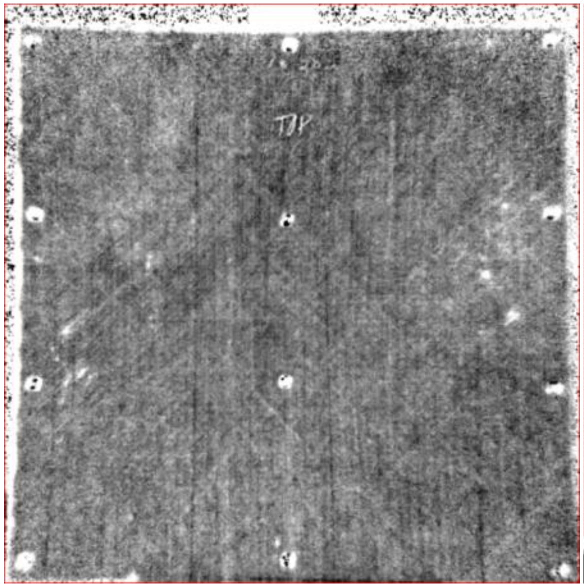

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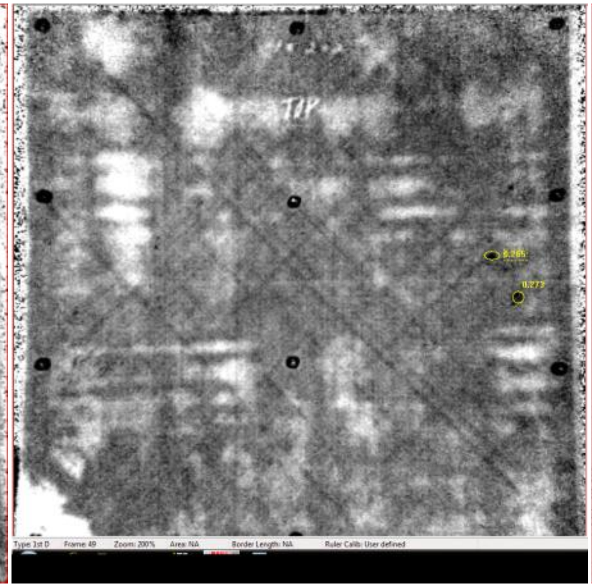
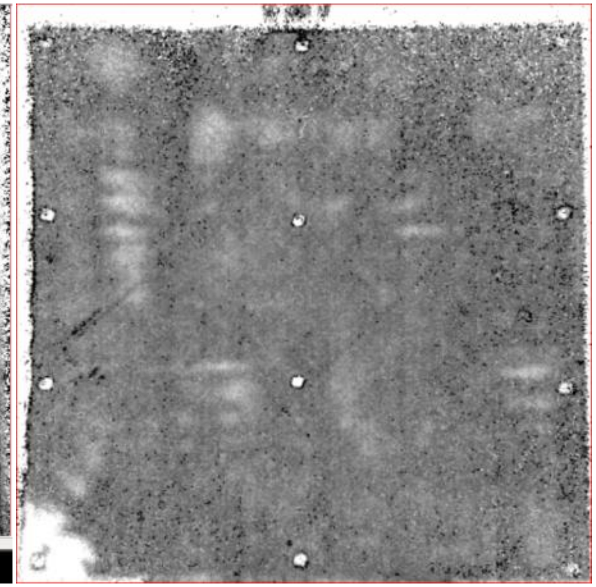
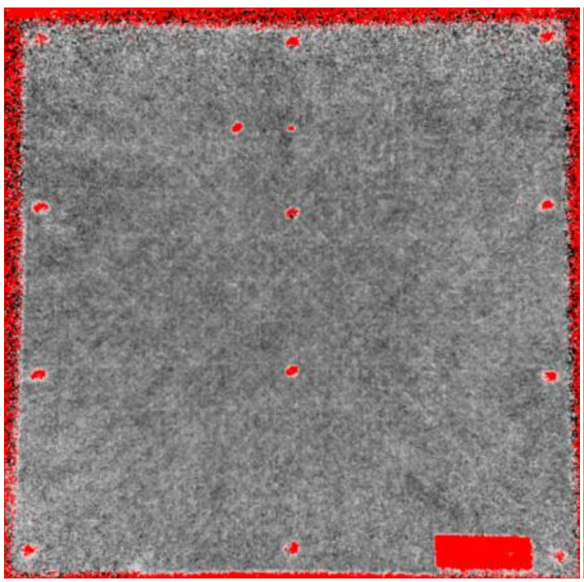


SN 18202 1d 1.0s voids



SN 18202 2d PA



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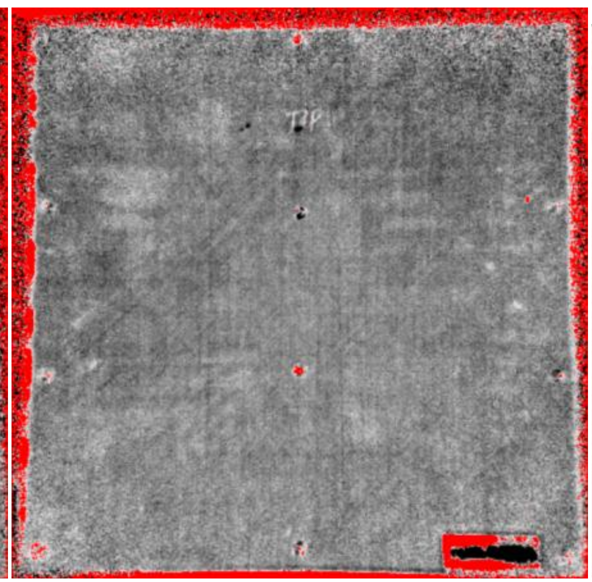
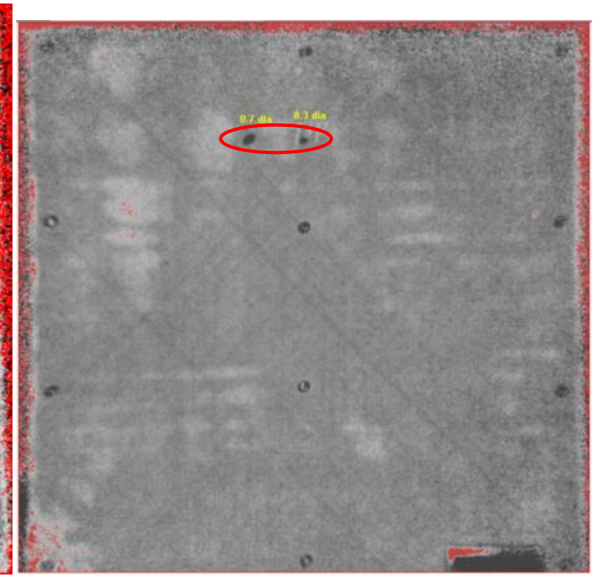
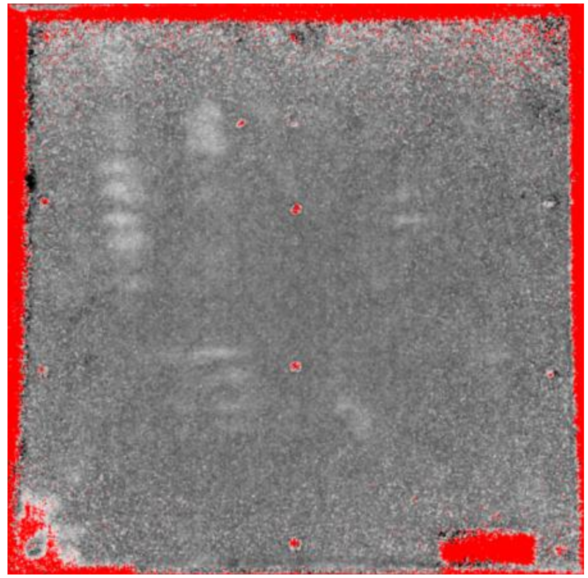


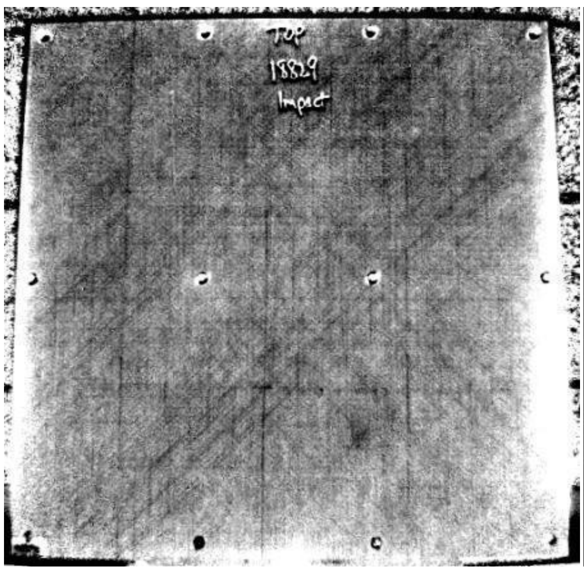
SN 18202 1d 0.42s post impact



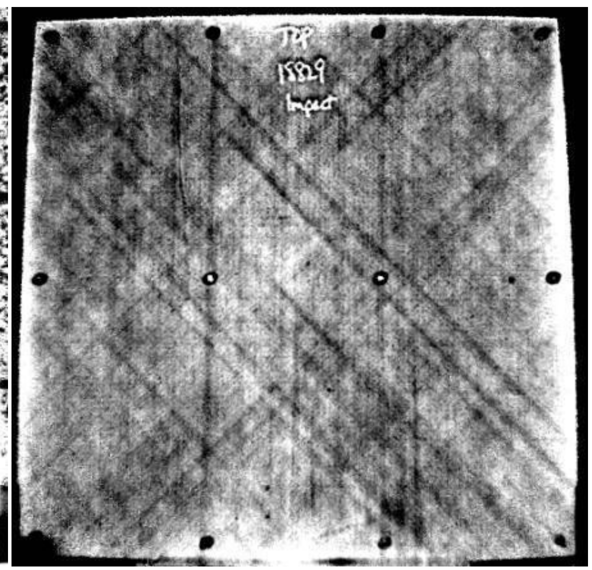
SN 18202 1d 1.0s voids post impact



SN 18202 2d PA post impact



SN18829 1d 0.42s



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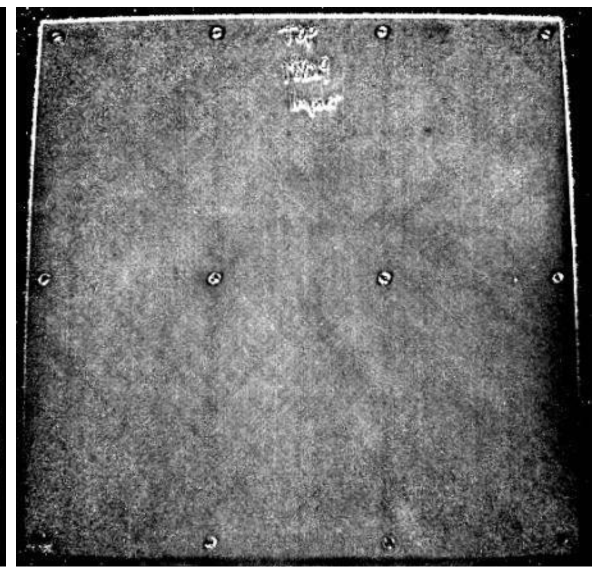
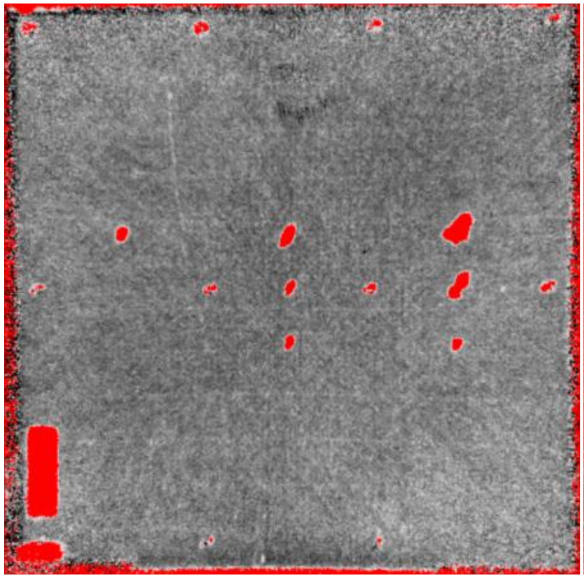


SN18829 2d PA



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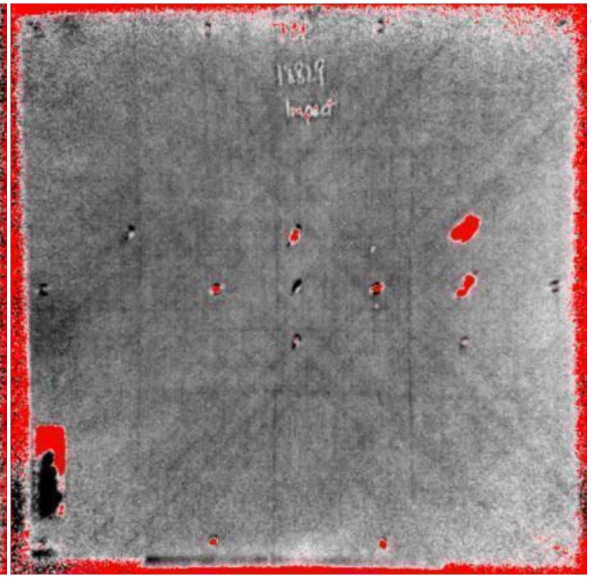

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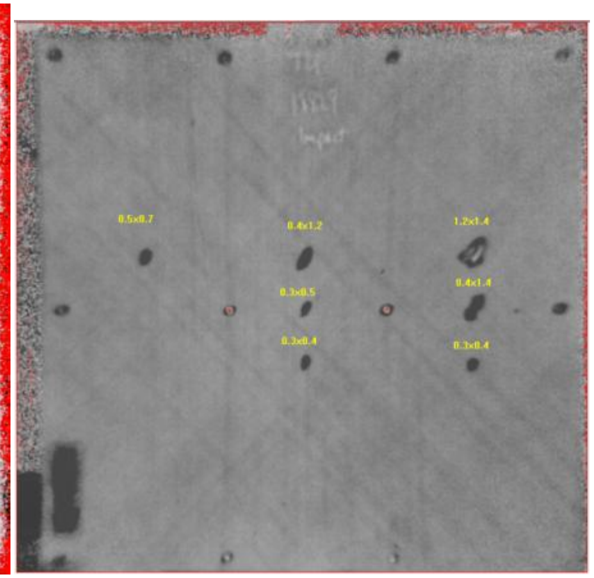

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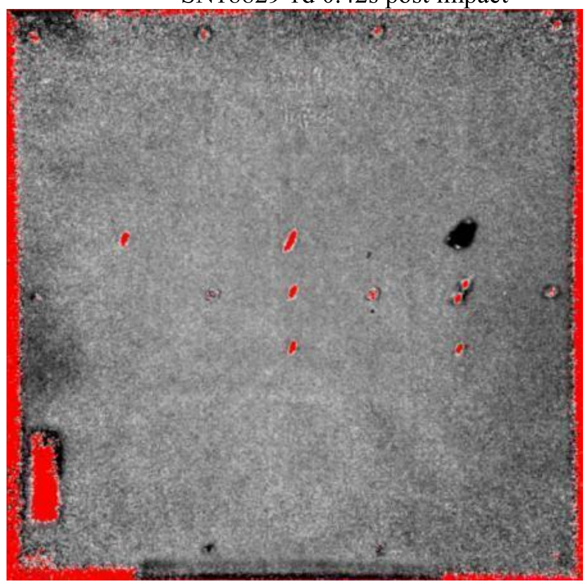
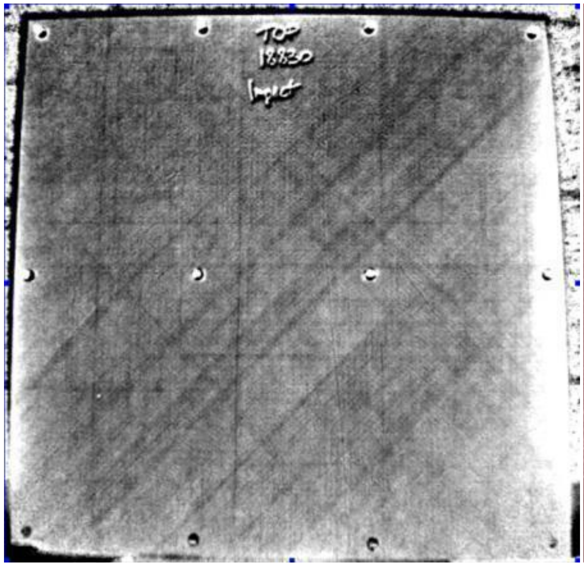


SN18829 2d PA Post impact



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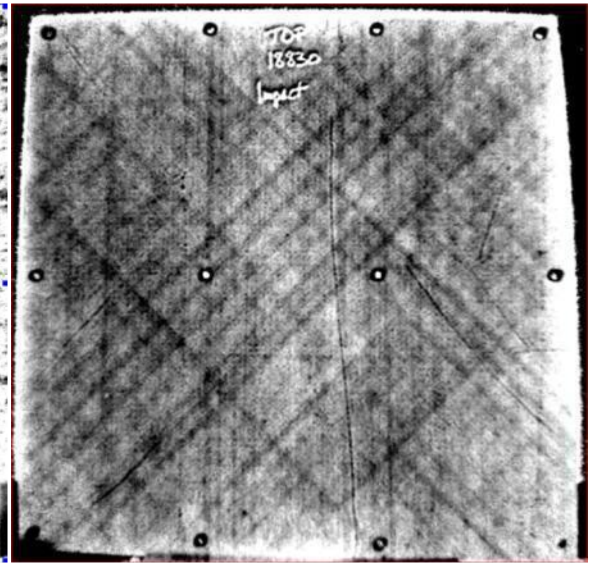
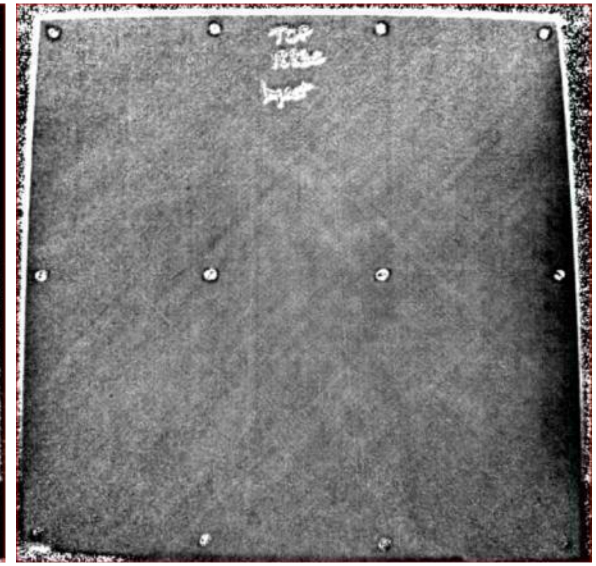
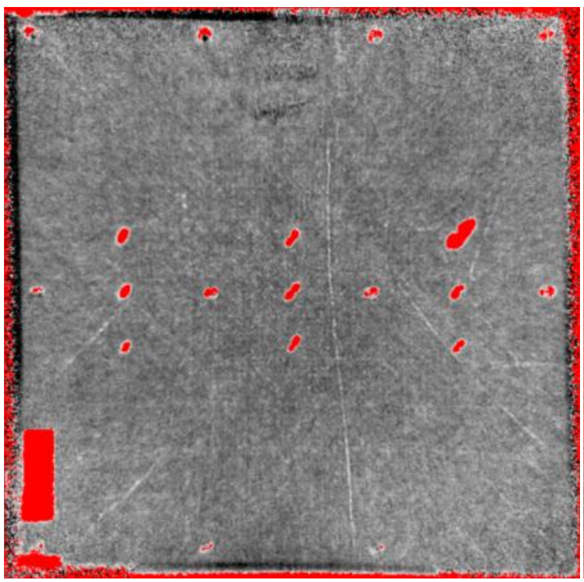


SN18830 1d 1.0s



SN18830 2d PA



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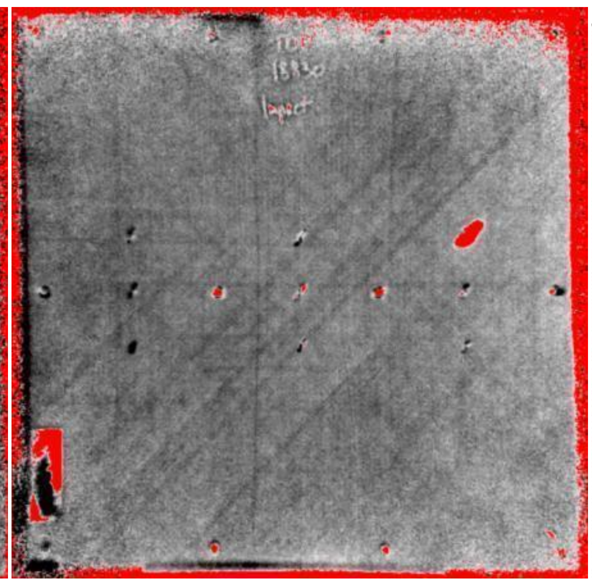
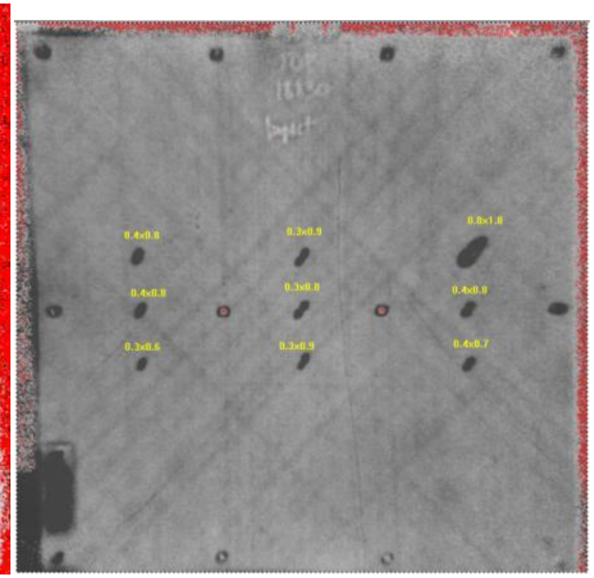
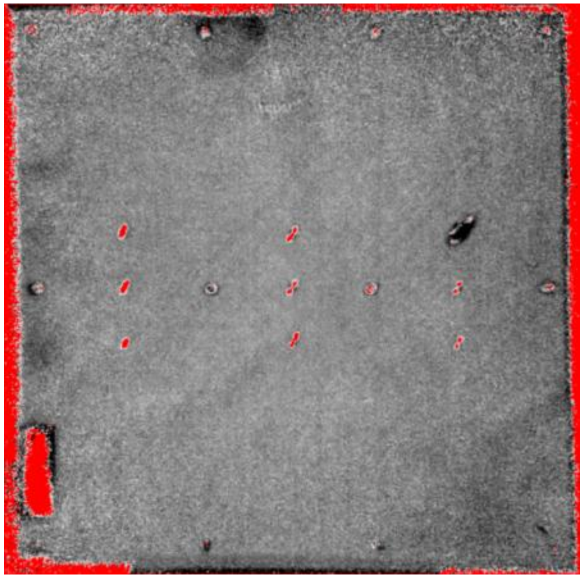


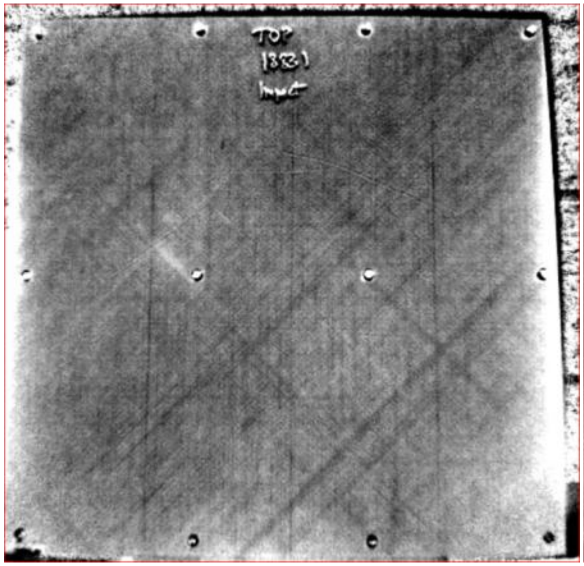
SN18830 1d 0.42s post impact



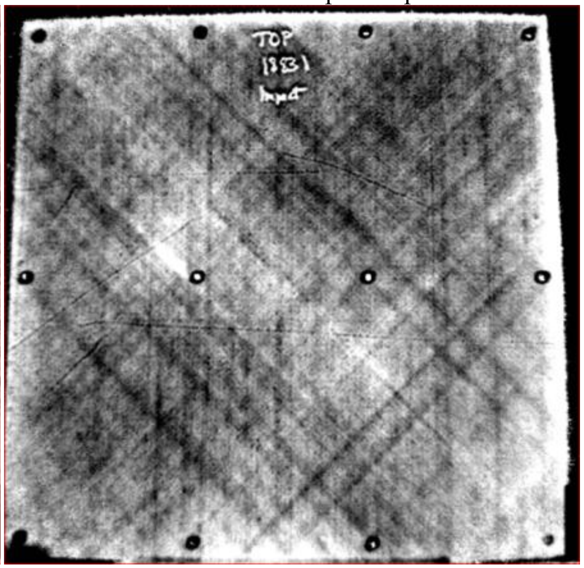
SN18830 1d 1.0s voids post impact



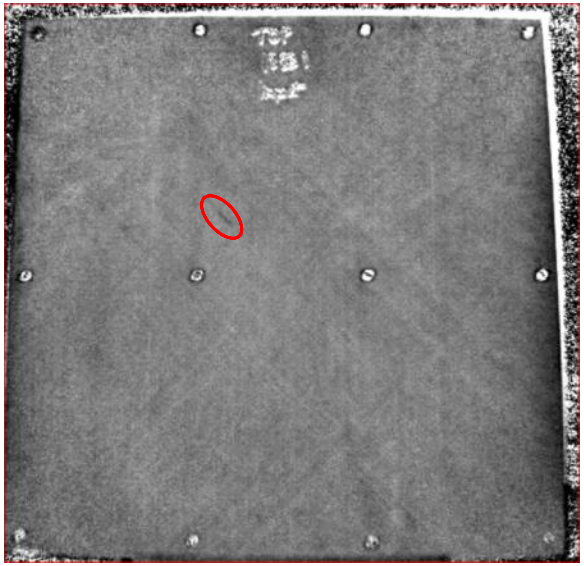
SN18830 2d PA post impact



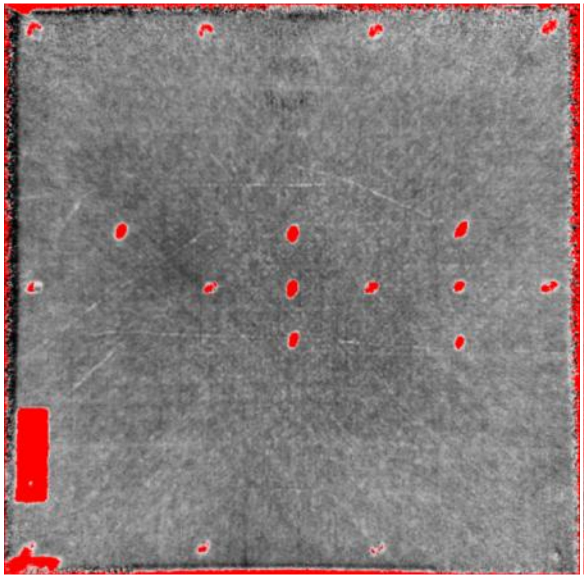
SN18831 1d 0.42s

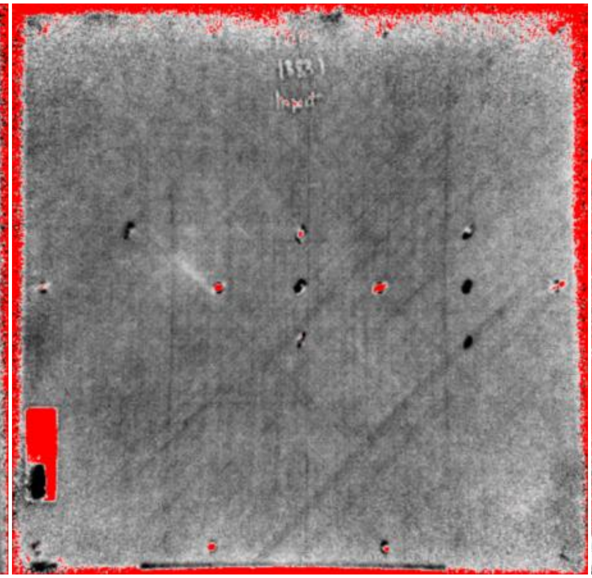


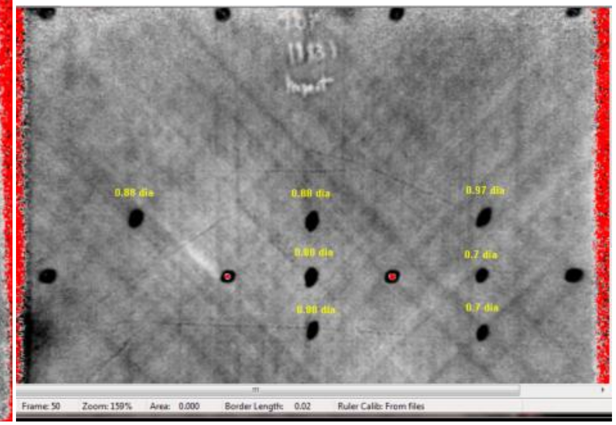
SN18831 1d 1.0s



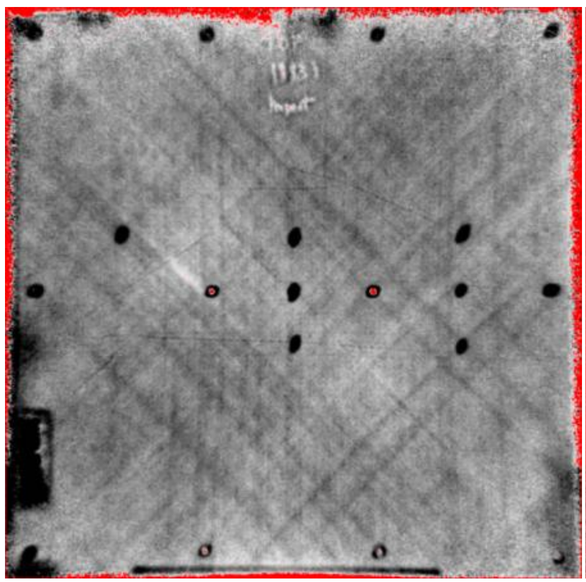
SN18831 2d PA

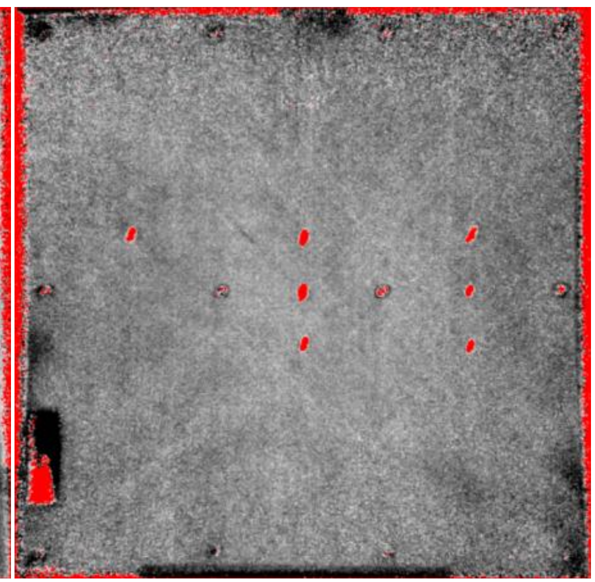

SN18831 1d 0.12s post impact


SN18831 1d 0.42s post impact



SN18831 1d 1.0s voids post impact


SN18831 1d 1.0s post impact


SN18831 2d PA post impact

Appendix K
Second-Generation Indirect Effects Test Data

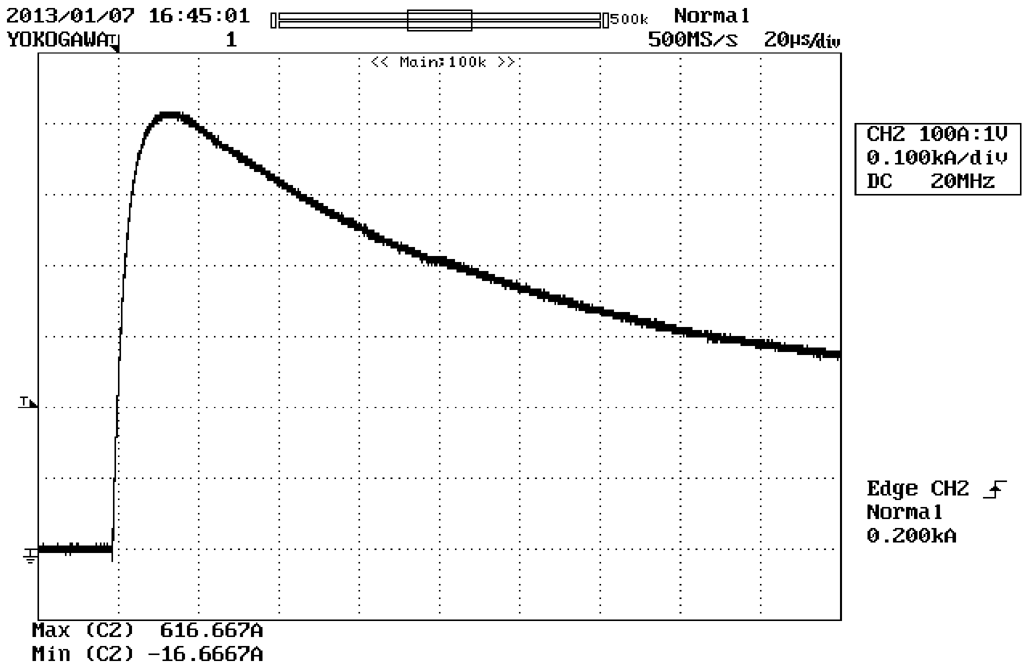


Figure K-1: Current calibration oscillogram input waveform with 616 A.

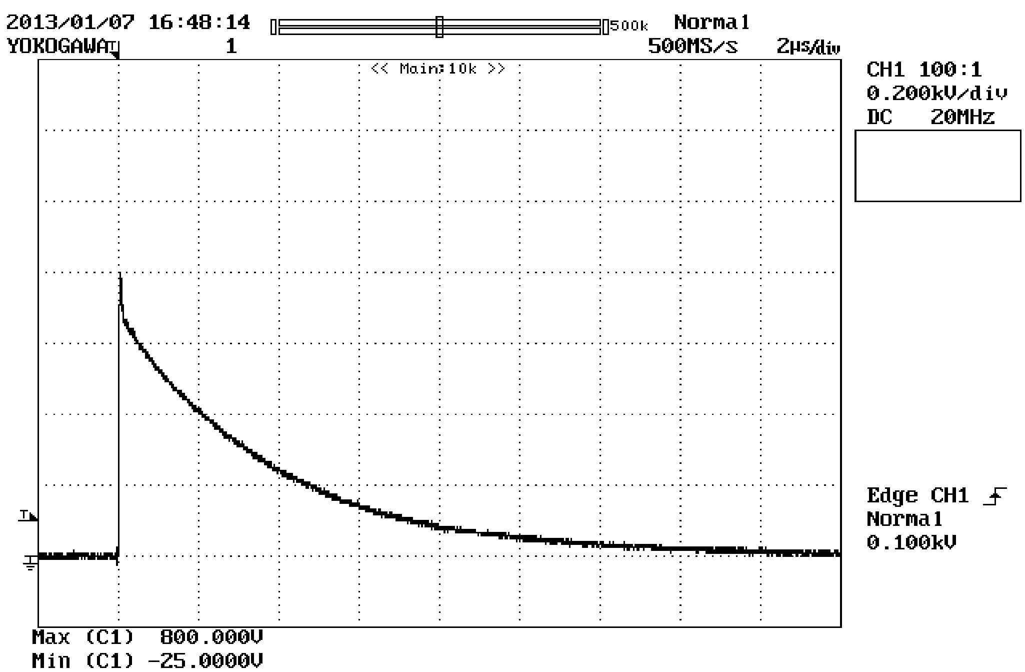


Figure K-2: Voltage calibration oscillogram waveform with 800 V.

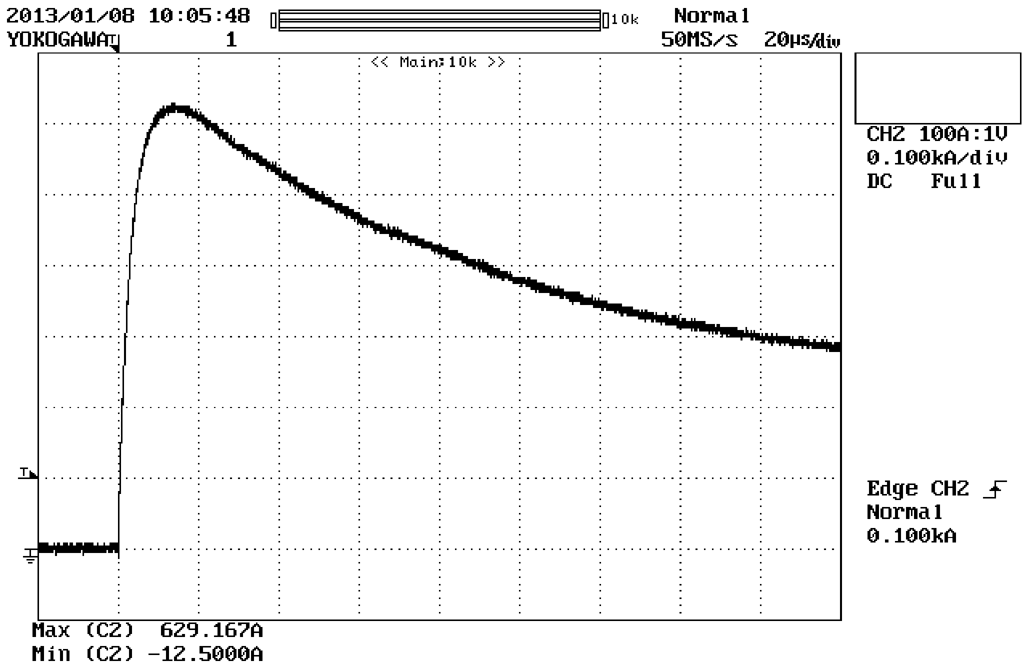


Figure K-3: Current calibration oscillogram with 629 A.

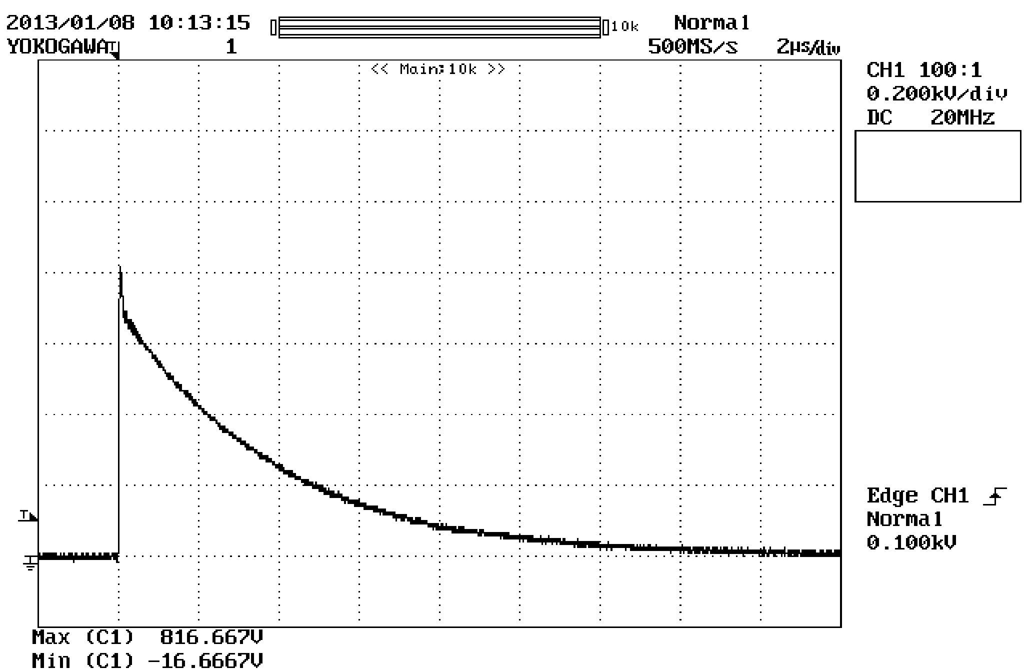


Figure K-4: Voltage calibration oscillogram with 816 V.

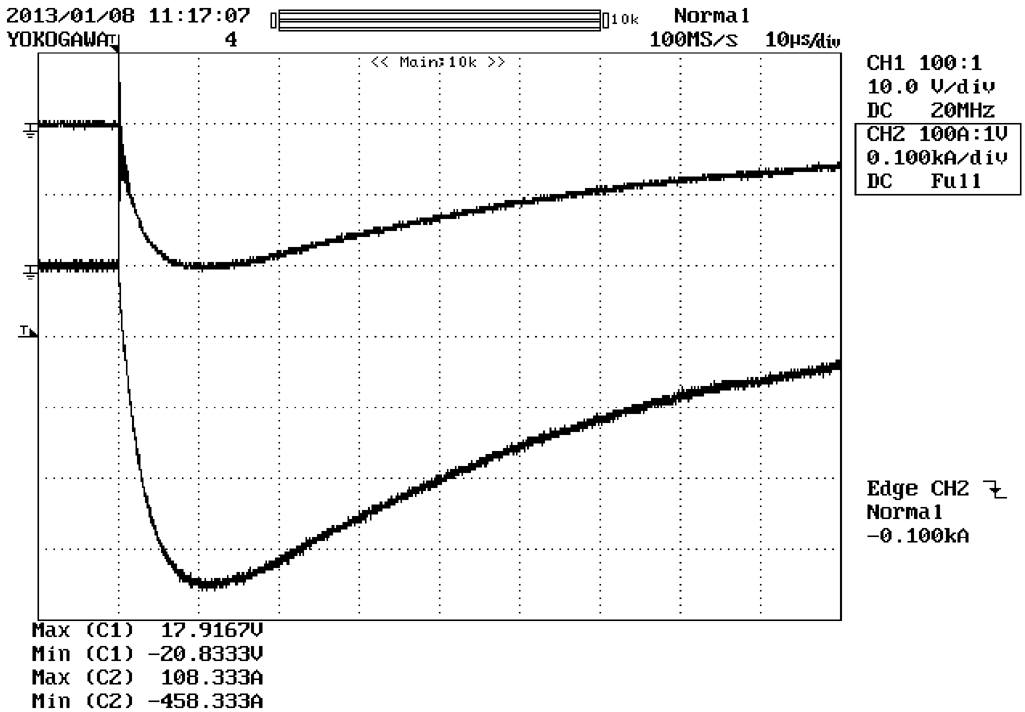


Figure K-5: Panel FLS-1 with voltage -20 V and current -458 A.

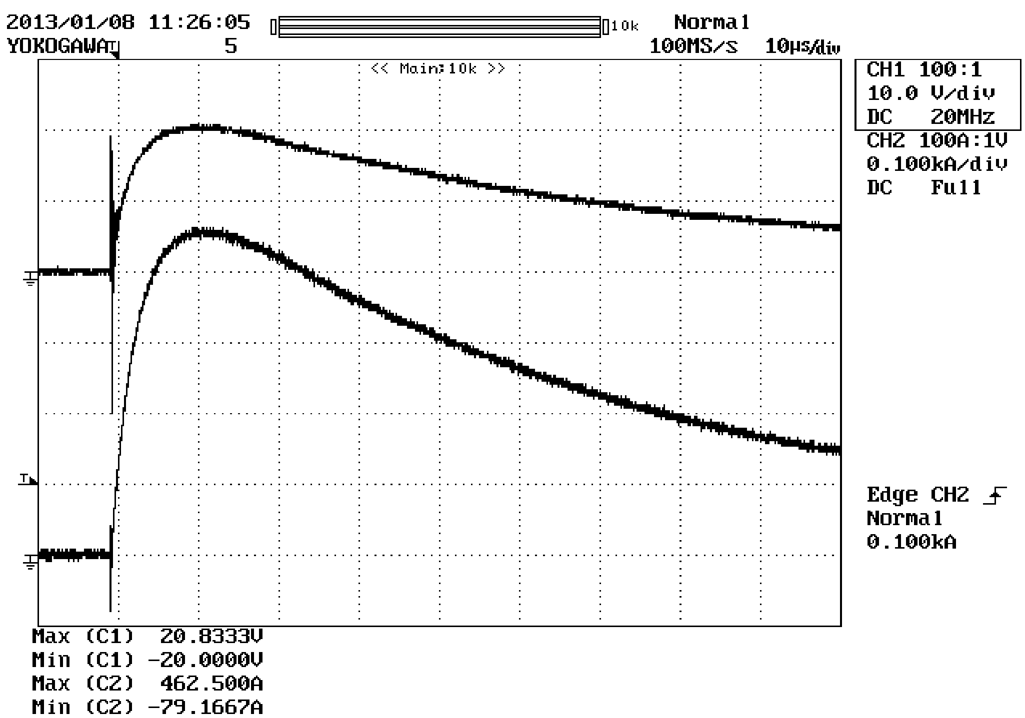


Figure K-6: Panel FLS-1 with voltage 20 V and current 462 A.

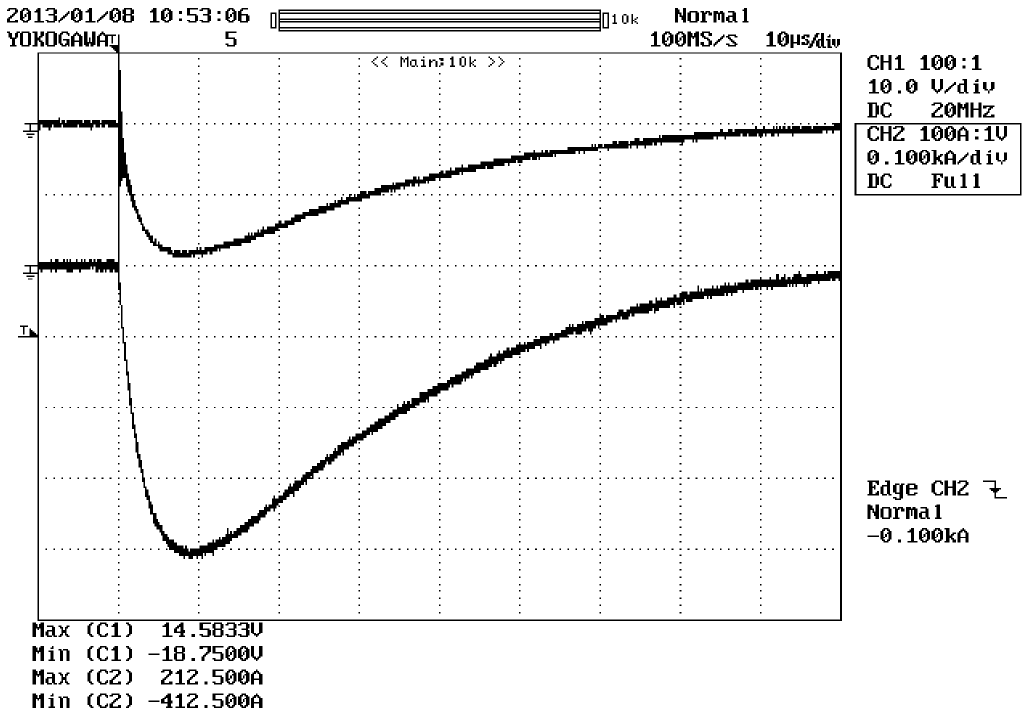


Figure K-7: Panel FLS 2 with voltage -18 V and current -412 A.

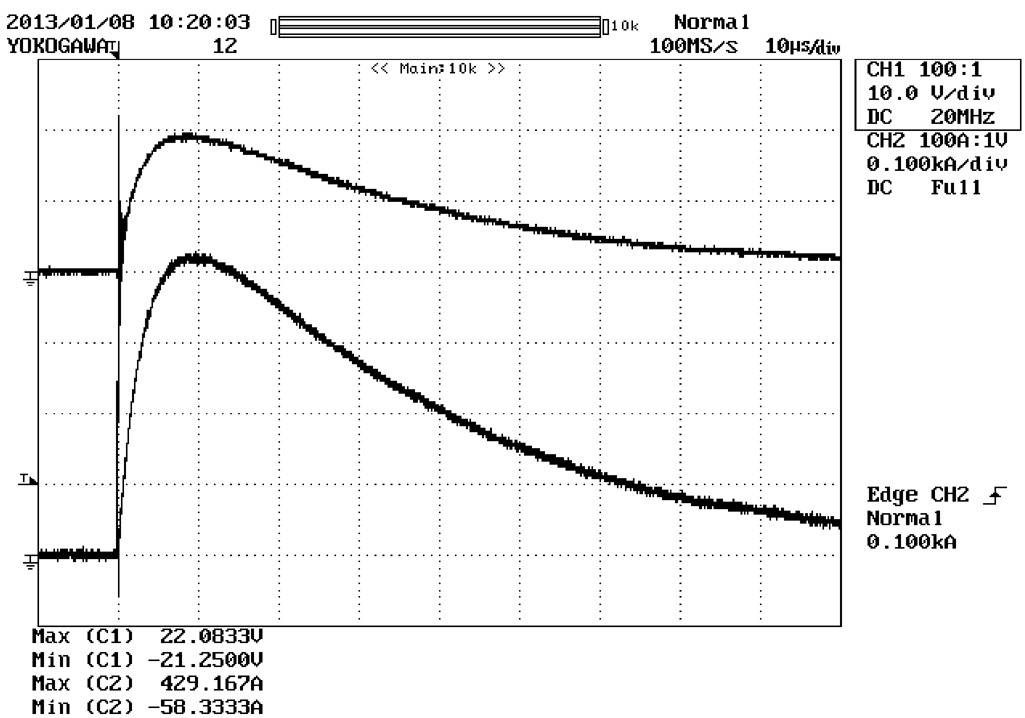


Figure K-8: Panel FLS-2 with voltage 22 V and current 429 A.

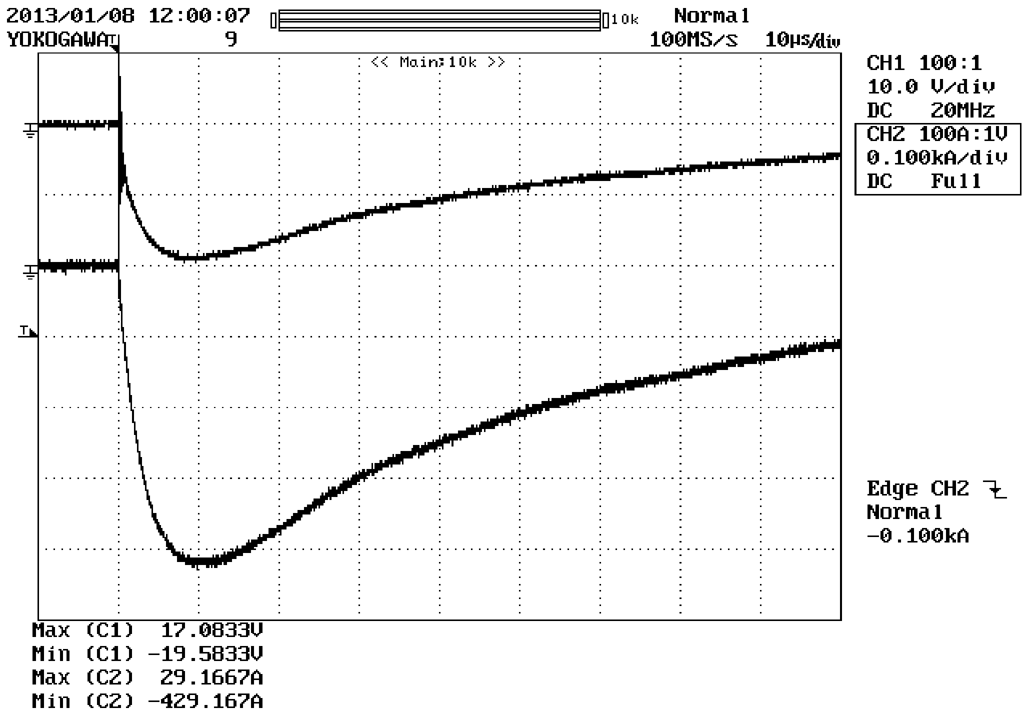


Figure K-9: Panel FLS-3 with voltage -19 V and current -429 A.

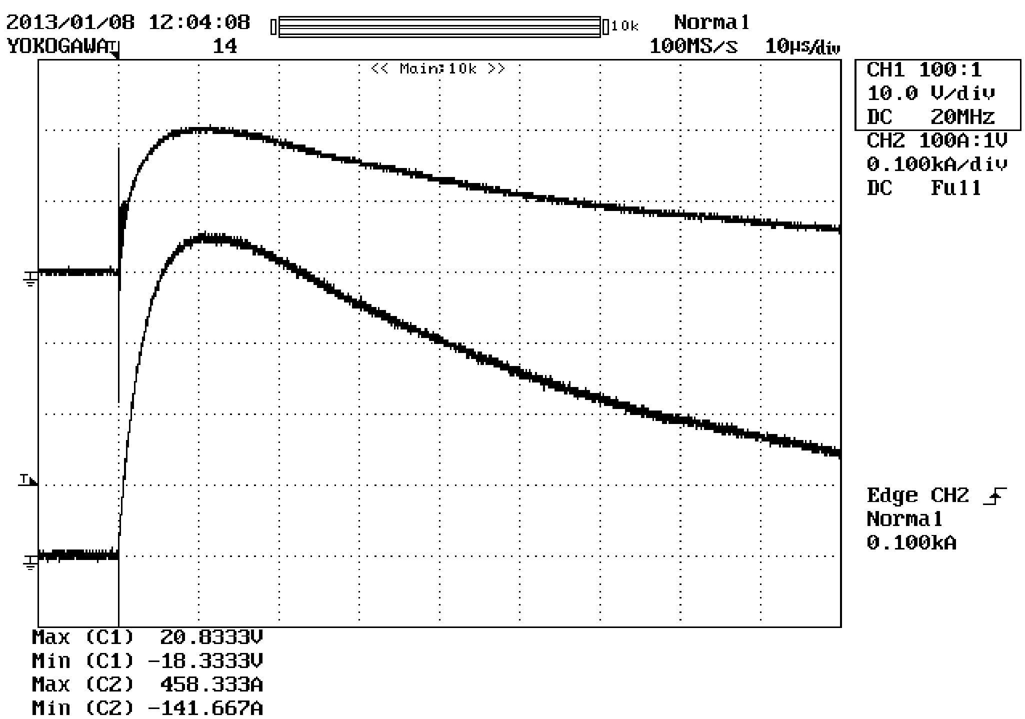


Figure K-10: Panel FLS-3 with voltage 20 V and current 458 A.

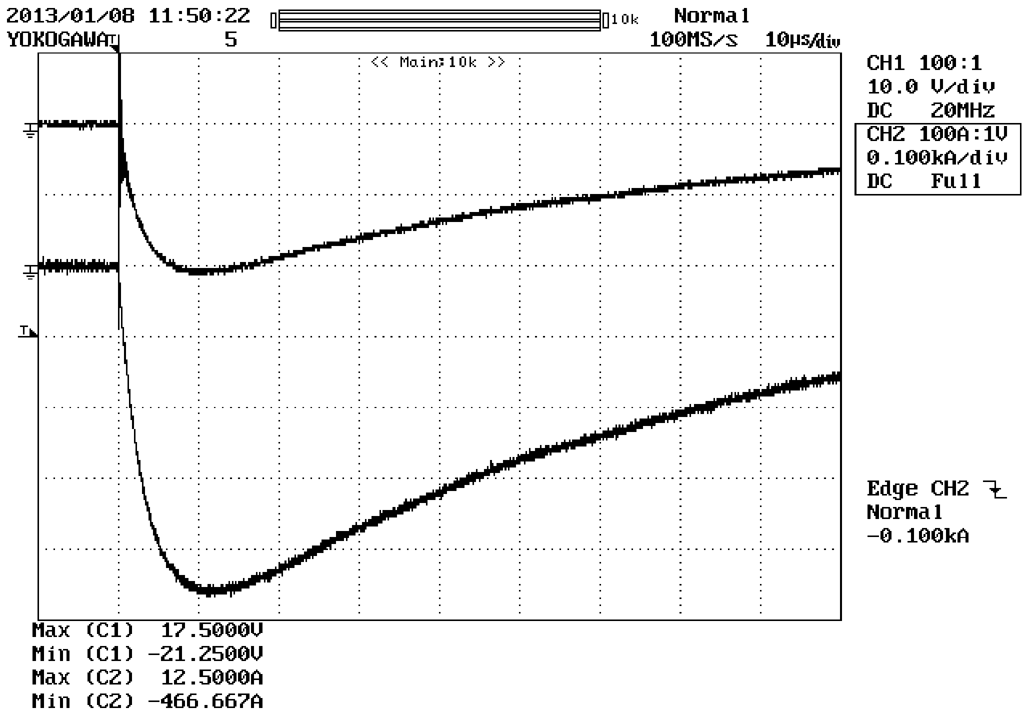


Figure K-11: Panel FLS-4 with voltage -21 V and current -466 A.

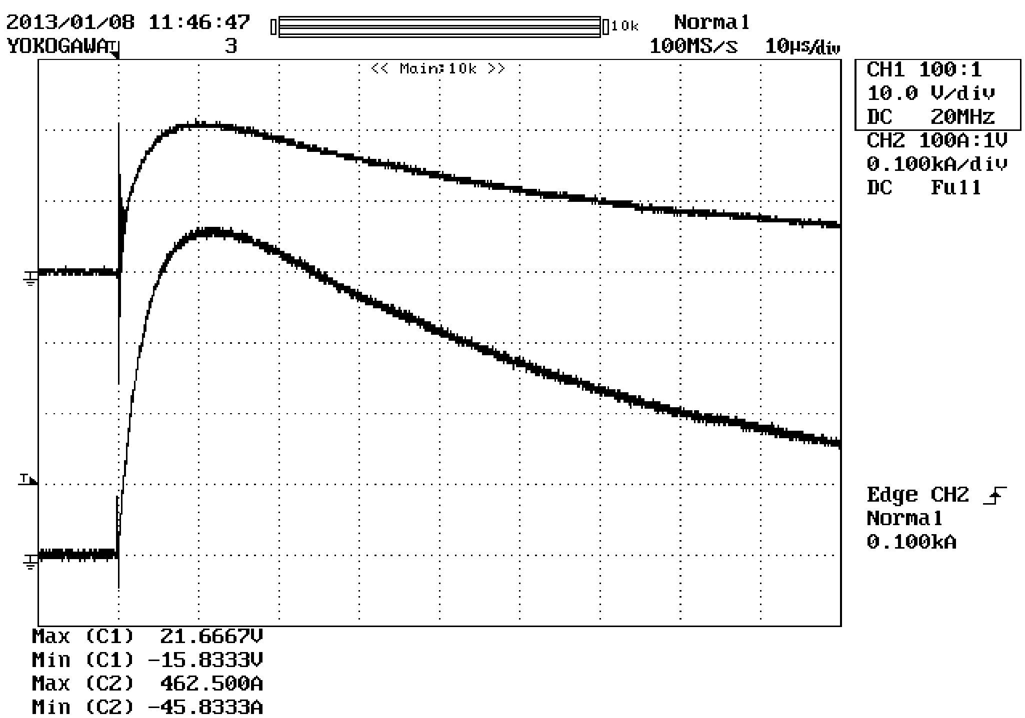


Figure K-12: Panel FLS-4 with voltage 21 V and current 462 A.

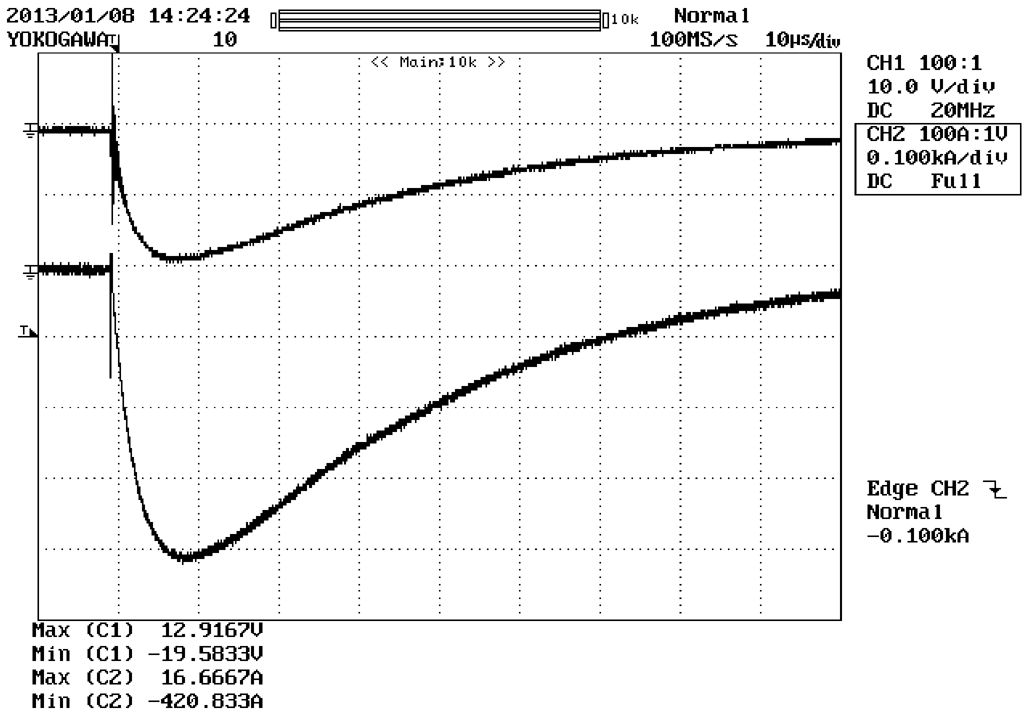


Figure K-13: Panel FLS-5 with voltage -19 V and current -420 A.

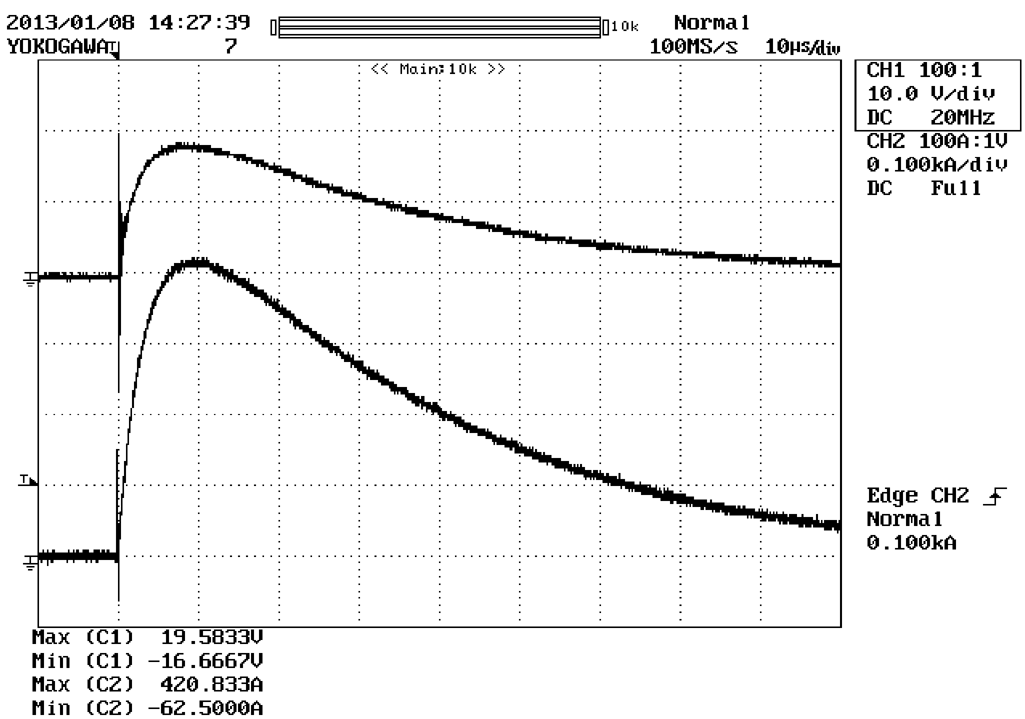


Figure K-14: Panel FLS-5 with voltage 19 V and current 420 A.

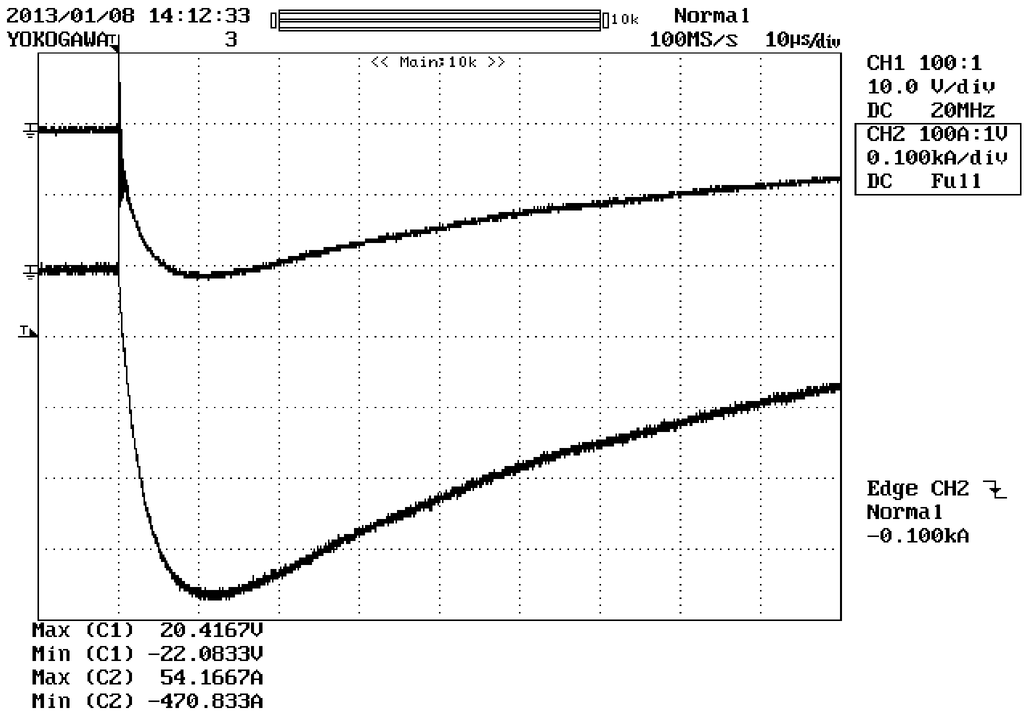


Figure K-15: Panel FLS-6 with voltage -22 V and current -470 A.

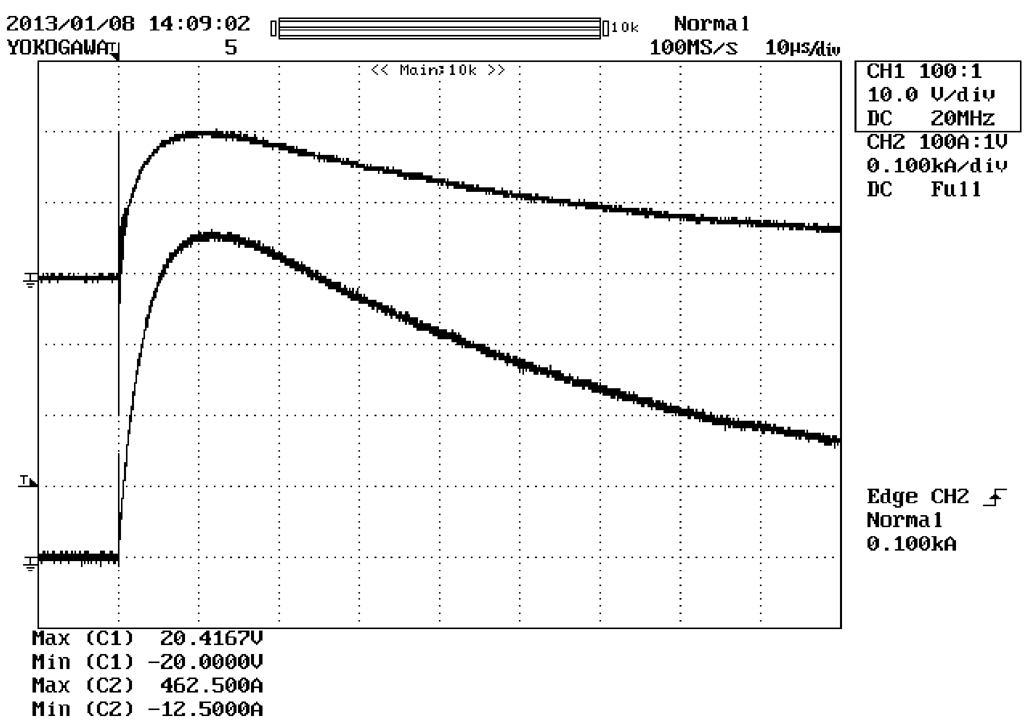


Figure K-16: Panel FLS-6 with voltage 20 V and current 462 A.

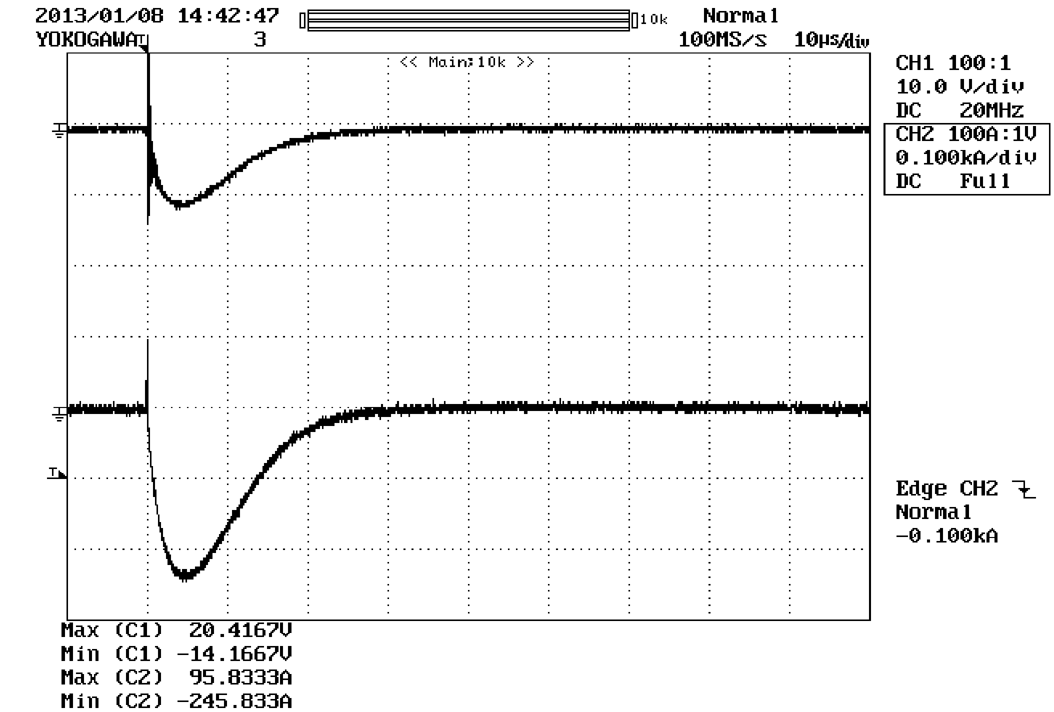


Figure K-17: Panel CFC with voltage -14 V and current -245 A.

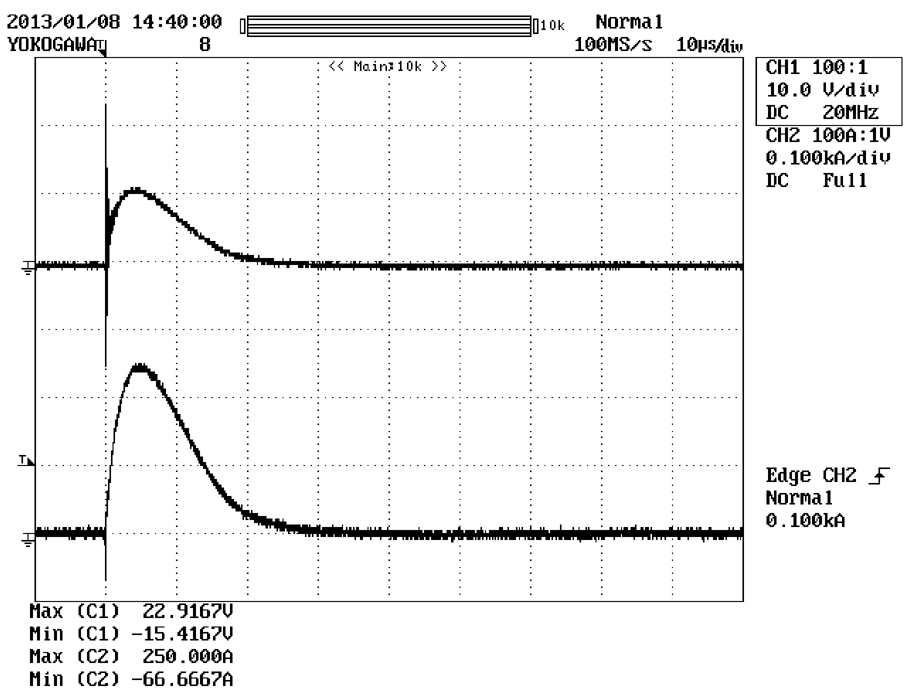


Figure K-18: Panel CFC with voltage 22 V and current 250 A.

Appendix L
Second-Generation Direct Effects Test Data and Pictures (DNB Engineering Report)

REVISIONS		
LTR	DESCRIPTION	DATE
-	INITIAL RELEASE	2-8-2013

PREPARED BY: S. COOK	DATE 2-8-13	**DNB ENGINEERING, INC.** FULLERTON, CA 92833 U.S.A.
TEST ENGINEER: S. COOK	2-8-13	LIGHTNING DIRECT EFFECTS TEST REPORT FOR THE
TEST DEPT. MGR: T. VU	2/08/13	COMPOSITE PANELS (SIX SAMPLES)
QUAL. ASSURANCE: M. NEIS DNB 2	2/11/13	PREPARED FOR: CESSNA AIRCRAFT CORPORATION PURCHASE ORDER NUMBER: CEDO504134

SIZE	CAGE CODE	DRAWING NO.
A	63242	TR057111/30147
SCALE: NONE	REV LTR -	SHEET 1

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5081 www.dnbenginc.com

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DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5 www.dnbenginc.com

APPENDICES

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5 www.dnbenginc.com

LIGHTNING DIRECT EFFECTS TEST COMPLETION RECORD

For

CESSNA AIRCRAFT CORPORATION

COMPOSITE PANELS (SIX SAMPLES)

Sample Numbers: FLS1 through FLS6

Test Start Date: 1-25-13 **Test Completion Date: 1-25-13**

Test Completion Record: The Composite Panels completed the High Current test in accordance with SAE ARP5416.

Lightning Direct Effects: The Customer will determine the Pass/Fail status of the test samples for this test.

DNB TEST ENGINEER ____________ DATE 2-8-13

DNB QUALITY ASSURANCE ____________ DATE 2/11/13

CUSTOMER TEST ENGINEER ____________ DATE ____________

SIZE	CAGE CODE	DRAWING NO.	
A	63242	TR057111	
SCALE: NONE		REV LTR -	SHEET 4

DNB ENGINEERING, INC. 3535 W. COMMONWEALTH AVE. FULLERTON, CA 92833 (714) 870-7781 FAX (714) 870-5 www.dnbenginc.com

1.0 INTRODUCTION

Lightning Direct Effect tests for Category 2A were performed on six Composite Panels, manufactured by Cessna Aircraft Corporation. Testing began on 1-25-13 and was completed on 1-25-13. The purpose of this test was to demonstrate compliance with the applicable sections of SAE ARP5416. All test results have been summarized herein, and all data sheets have been incorporated in Appendix D.

2.0 TEST REQUIREMENTS

The test requirements for the tests performed as outlined in this document are defined by the applicable sections of SAE ARP5416.

3.0 TEST EQUIPMENT

The test equipment log in Appendix B lists information on test equipment used, along with current calibration status. DNB's calibration service providers use procedures provided by the manufacturers and by other widely recognized bodies (for example, GIDEP). Standards used during calibration are traceable to NIST.

SUMMARY OF TEST RESULTS

Lightning Direct Effects, SAE ARP5416 Introduction

Direct Effect Lightning tests for Category 2A were performed on the six Composite Panels which included High Current tests.

High Current Test

High Current calibration and tests were performed with the high current generator configured for negative polarity. The electrode was placed 50 mm above the Composite Panel. A leader wire was connected to the electrode and positioned just above the Composite Panel. An aluminum panel was used for the calibration. High current components D, B, and C* were then applied. This was done for the aluminum panel and the forty four Composite Panels. The following waveforms were applied to the Composite Panels:

Component D: I_P = 100 KA +/-10%; Action Integral = 2.5E5 A^2-S +/-20%
Component B: I_{avg}=2000 Amps +/-10%; Charge Transfer@5 mS=10 Coulombs +/-20% Component C*: I_{avg} = 400 Amps +/-10%; Charge Transfer = 18 Coulombs +/-20% Component A: I_P = 200 KA +/-10%; Action Integral = 2.0E6 A^2-S +/-20%

SIZE A	CAGE CODE 63242	DRAWING NO. TR057111
SCALE: NONE	REV LTR -	SHEET 5

4.1 Lightning Direct Effects *(Continued)*

High Current Test

A metal strip was placed on the back side of the Composite Panel to simulate a wiring bundle or fuel line. This is done as a worst case setup to try and induce a puncture. The metal strip was connected to ground with a 30 awg fuse wire. After each strike, the wire was checked to see if there was enough current coupled to the metal strip to open the fuse wire. After the completion of the six panels, two panels were selected for a Zone 1A strike and were tested with Components A, B, and C*.

Pre and Post Functional Test Data

If applicable, the Composite Panels were checked for proper functionality prior to the direct effects lightning tests. After completion of the direct effects lightning tests, the Composite Panels were again checked for proper functionality. Any available pre and post functionality data is provided in a separate Cessna Aircraft Corporation document.

4.1 Lightning Direct Effects *(Continued)*

Test Results

The Composite Panels showed varying degrees of damage. None of the Composite Panels showed any signs of puncture. None of the strikes caused the fuse wire to open.

Test Log

The Test Log is provided in Appendix A. Test Equipment

A list of the test equipment used to perform all testing complete with calibration dates is provided in Appendix B.

Test Data

Test Data are provided in Appendix D. Test Photographs

Test photographs are provided in Appendix E. Disposition of Test Samples

Following testing, the Composite Panels were returned to Cessna Aircraft Corporation for further evaluation.

Bonding Measurements

Bonding measurements were not performed during these tests.

5.0 TEST DESCRIPTION

The test method and description, including details of the test set-up and test figures are described in SAE Arp5416 for each of the lightning tests. A list of the test equipment used in the performance of each of these tests, along with current calibration information is included in Appendix B. Photographs of each test setup were taken and are included in Appendix E.

6.0 CONCLUSIONS

The Composite Panels completed the direct effects lightning tests in accordance with SAE ARP5416. Upon the completion of testing, the test sample and all applicable Cessna Aircraft Corporation support equipment were returned to representatives of Cessna Aircraft Corporation.

The results listed in this report relate only to the items tested as listed on the Test Completion Record on sheet 4 herein.

APPENDIX A
Test Log

SIZE	CAGE CODE	DRAWING NO.
A	63242	TR057111

SCALE: NONE	REV LTR -	SHEET A1

LIGHTNING TEST LOG

CUSTOMER: CESSNA	TEST SAMPLE: JET DIVERTING ELECTRODE STUDY
TEST ENGINEER: STEVE COOK	CUSTOMER REPRESENTATIVE: VANDANA PENDSE

DATE	TIME	TEST DESCRIPTION
1-25-13	8:00	Setting up for high current test.
	10:00	Panel FLS-3 – first strike
	10:20	Panel FLS-3 – second strike
	11:00	Panel FLS-4 – first strike
	11:20	Panel FLS-4 – second strike
	11:50	Panel FLS-5 – first strike
	12:15	Panel FLS-5 – second strike
	1:35	Panel FLS-6 – first strike
	2:00	Panel FLS-6 – second strike
	2:25	Panel FLS-1 – first strike
	2:45	Panel FLS-1 – second strike
	3:15	Panel FLS-2 – first strike
	3:40	Panel FLS-2 – second strike
	4:15	Panel FLS-6 Zone 1A
	4:50	Panel FLS-1 Zone 1A
	5:00	Testing completed.

APPENDIX B
Test Equipment Log

SIZE	CAGE CODE	DRAWING NO.
A	63242	TP057111

SCALE: NONE	REV LTR -	SHEET B1

TEST EQUIPMENT LOG

DIRECT EFFECT LIGHTNING

MANUFACTURER	DESCRIPTION	MODEL NO.	SERIAL NO.	CAL DUE
DNB	COMPONENT A/D GENERATOR	100KV200KA	001	CPT
DNB	COMPONENT B GENERATOR	15KV2160	001	CPT
DNB	COMPONENT C GENERATOR	72900VDC	001	CPT
PEARSON	CURRENT PROBE – A/D	1423	2343	11-30-13
PEARSON	CURRENT PROBE – B	301X	1212	10-14-13
DNB	CURRENT PROBE – C	HMHB100	12364	12-14-13
YOKOGAWA	SCOPECORDER	DL750	12B07030H	1-16-14
BIRD	20 dB ATTENUATOR	150-SA-FFN-20	162467	8-25-13
BIRD	20 dB ATTENUATOR	150-SA-FFN-20	0219	8-25-13

CPT – Calibration performed prior to test.

APPENDIX C
Transducer Factors

N/A

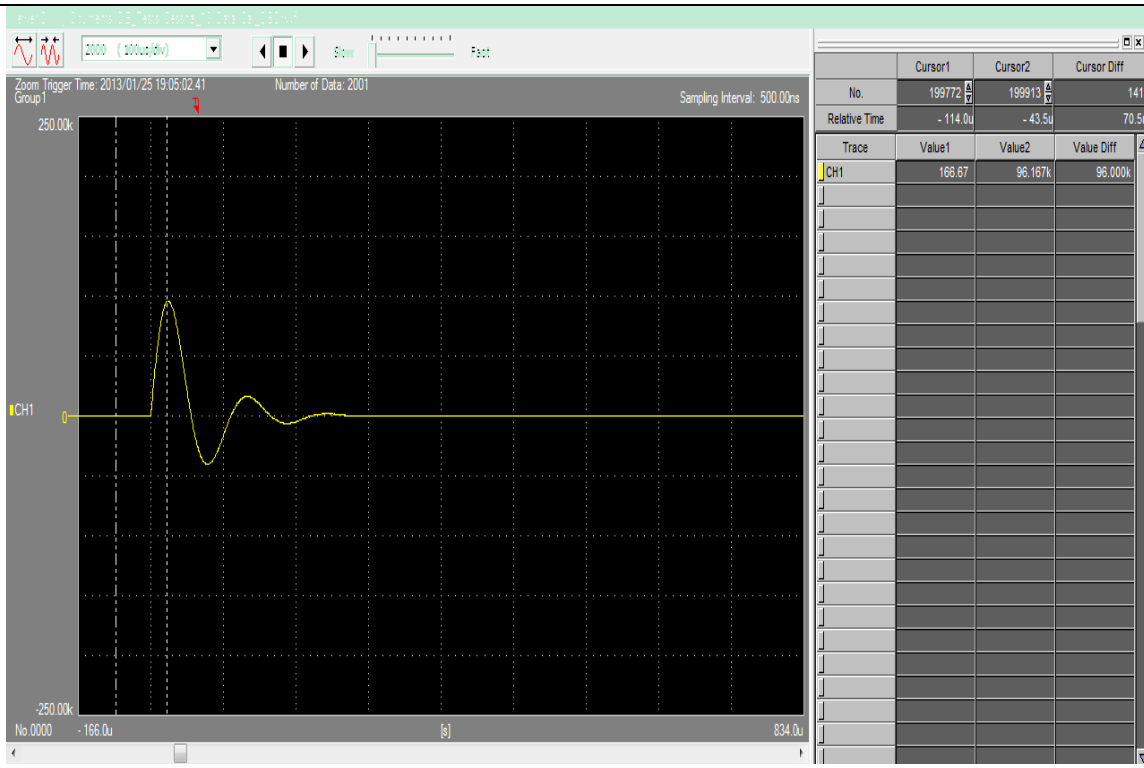
SIZE	CAGE CODE	DRAWING NO.
A	63242	TR057111

SCALE: NONE	REV LTR -	SHEET C1

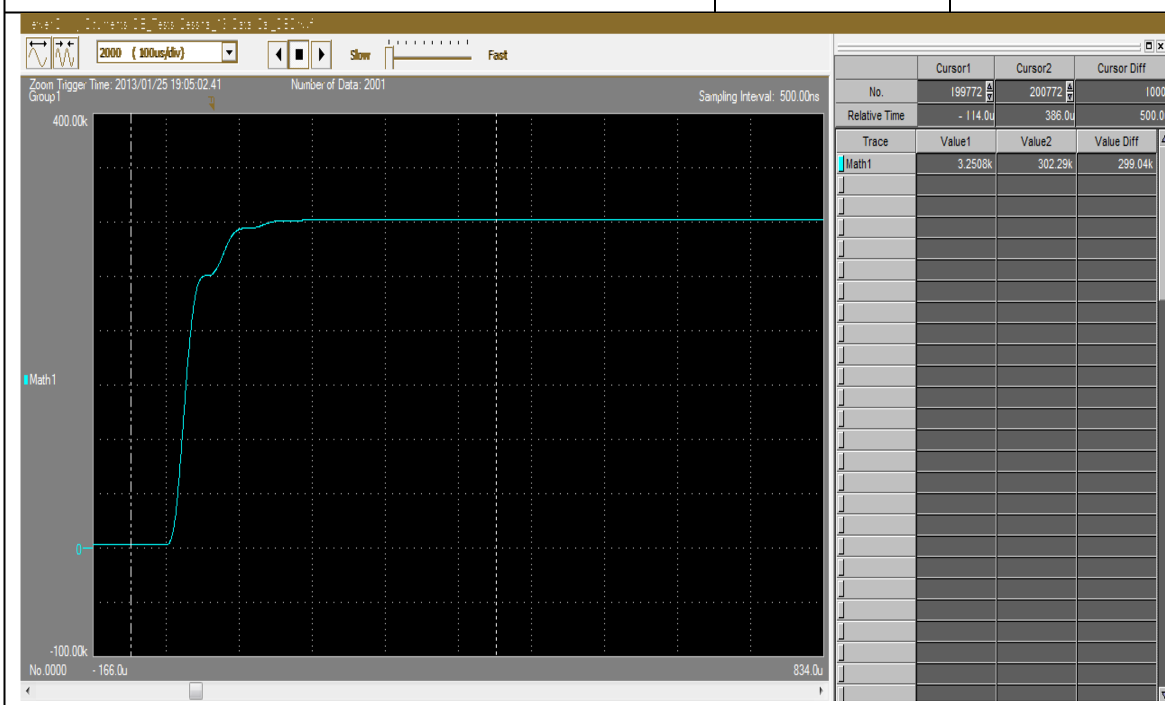
APPENDIX D
Test Data

DIRECT EFFECT LIGHTNING TEST SUMMARY

Test	Comp. D I_P (KA)	Comp. D AI (A^2S)	Comp. B I_{Avg} (Amps)	Comp. B CT (C)	Comp. C* I_P (Amps)	Comp. C* CT (C)
Cal	96.0	299040	2320	11.598	491	18.5
FLS1	94.0	271700	2266	11.331	267	4.0
FLS1	93.0	264240	2242	11.211	138	0.25
FLS2	94.7	276410	2169	10.847	425	20.0
FLS2	93.7	270370	2174	10.869	416	21.4
FLS3	94.8	278350	2229	11.145	348	4.2
FLS3	93.7	268330	2249	11.247	217	1.1
FLS4	93.3	268460	2222	11.112	177	0.007
FLS4	91.5	251490	2268	11.339	291	1.1
FLS5	94.2	274060	2226	11.130	417	21.1
FLS5	94.2	275950	2177	10.886	421	21.2
FLS6	92.3	248950	2244	11.218	146	0.55
FLS6	90.2	256950	2099	10.496	100	0.41
FLS1	185.0	1.9259E6	2473	12.366	508	20.0
FLS6	186.2	2.0085E6	2438	12.189	498	18.2

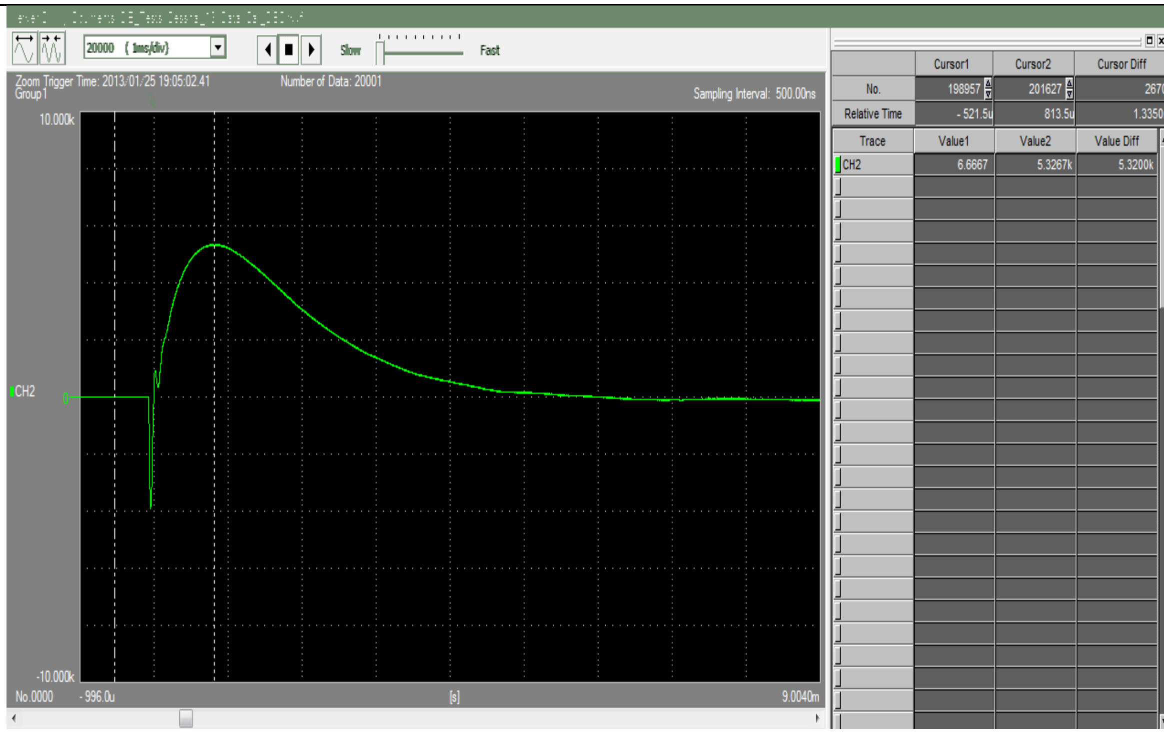


HIGH CURRENT – COMPONENT D	I_P = 96.0 KA	100 uS / Div

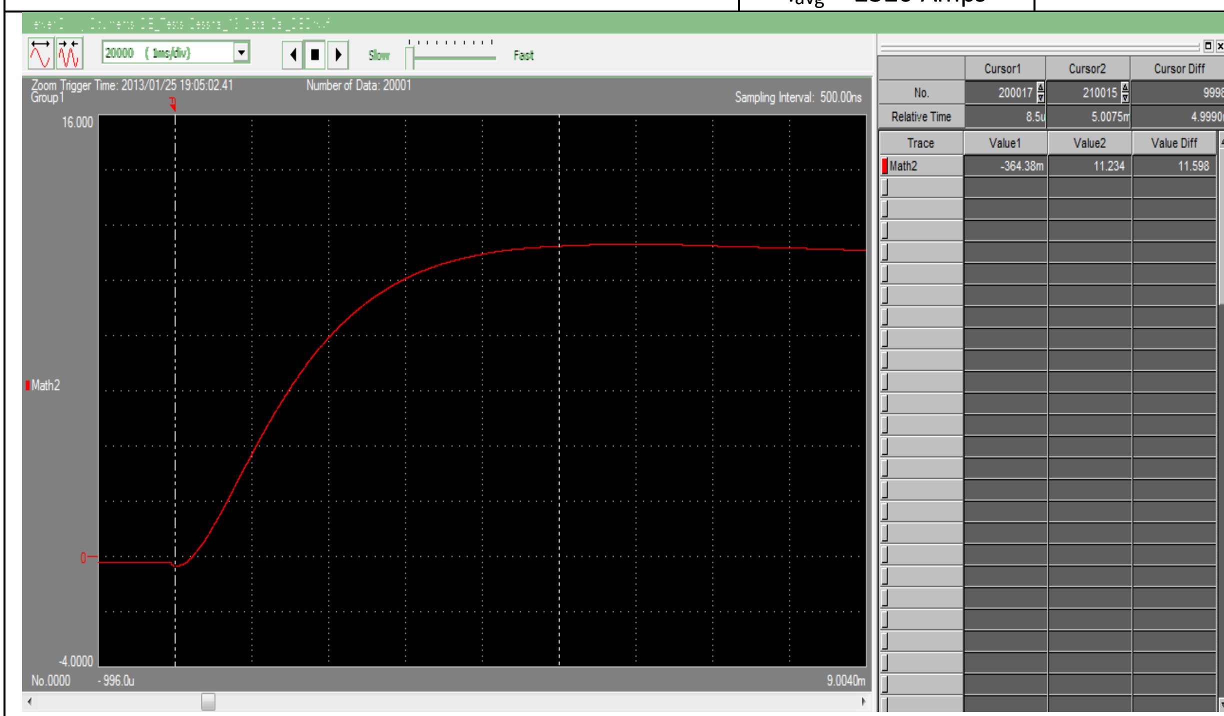


COMPONENT D ACTION INTEGRAL	AI = 299040 A^2- S

CALIBRATION

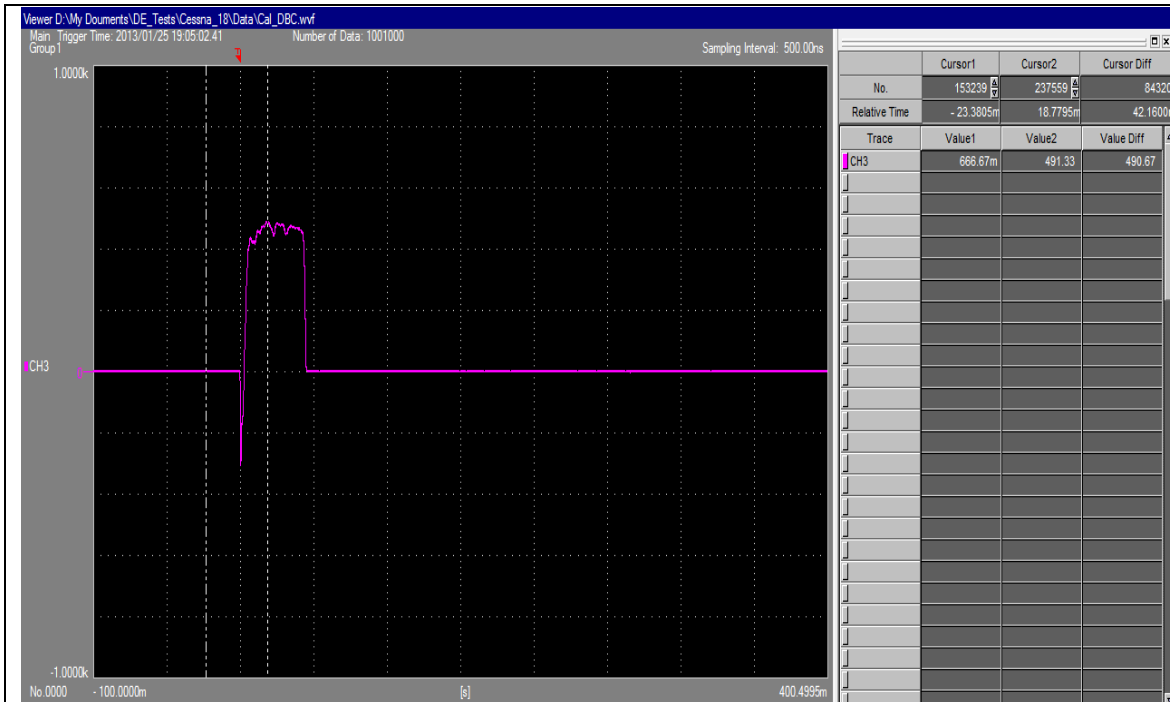


HIGH CURRENT – COMPONENT B	I_P = 5320 Amps I_{avg} = 2320 Amps	1 mS / Div

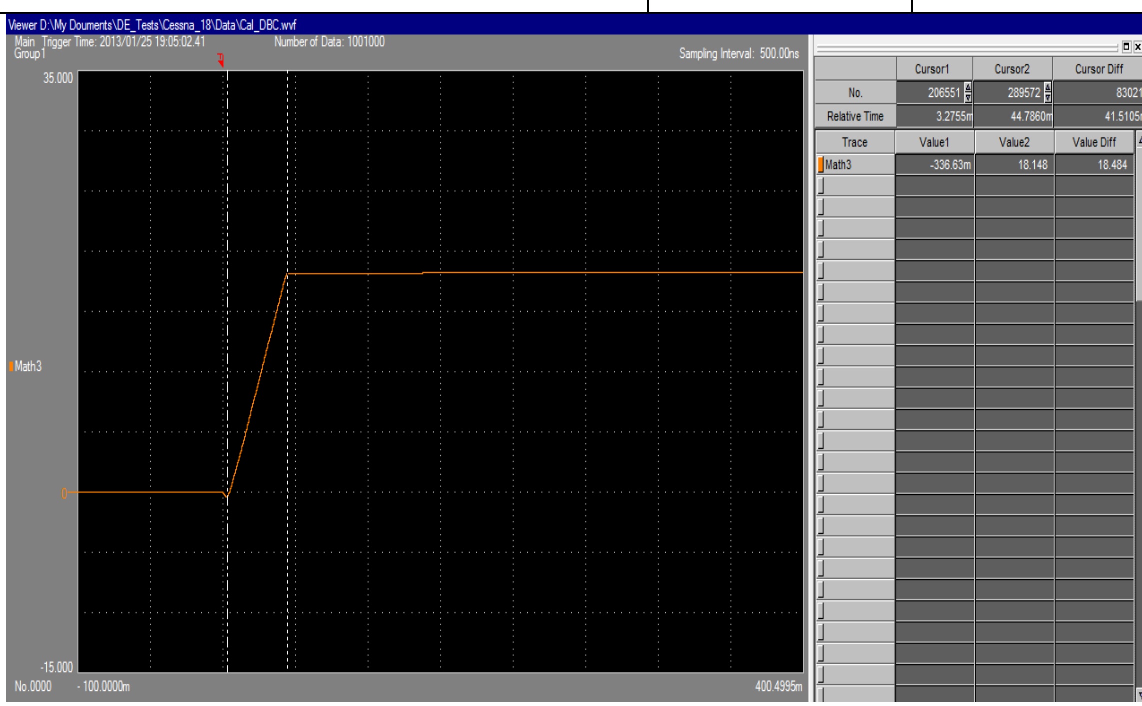


COMPONENT B CHARGE TRANSFER	11.598 Coulombs

CALIBRATION

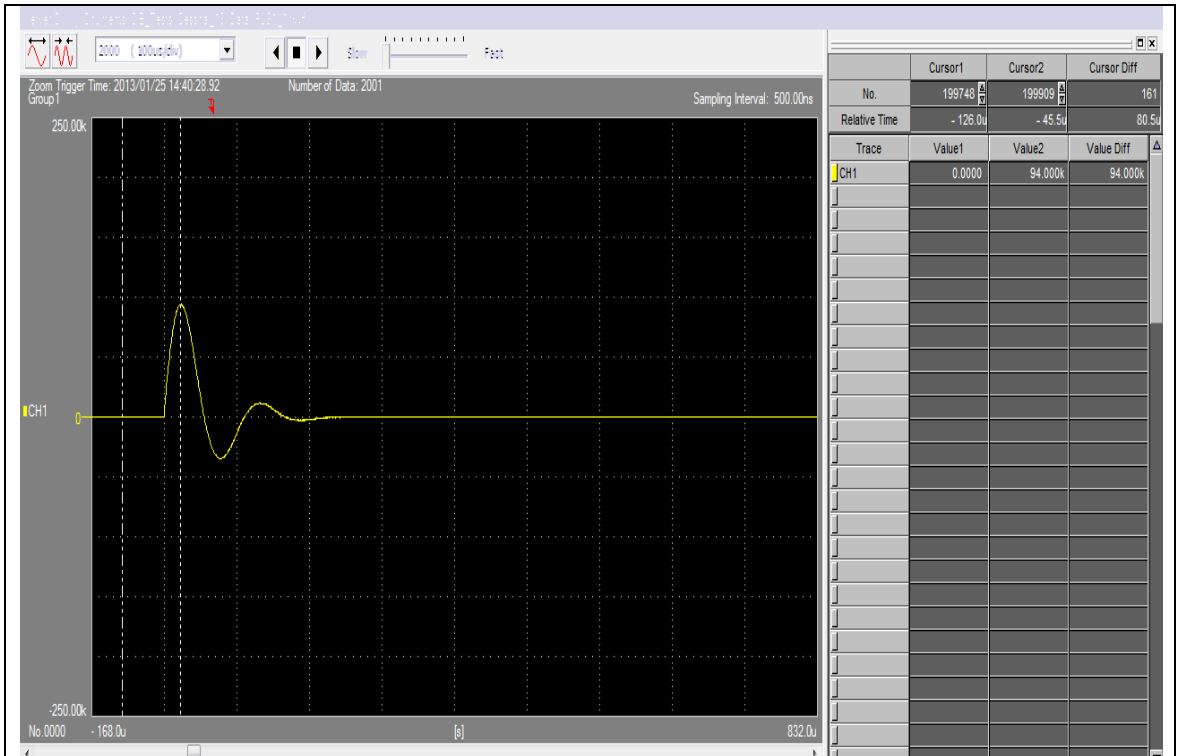


HIGH CURRENT – COMPONENT C*	I_P = 491 Amps	50 mS / Div

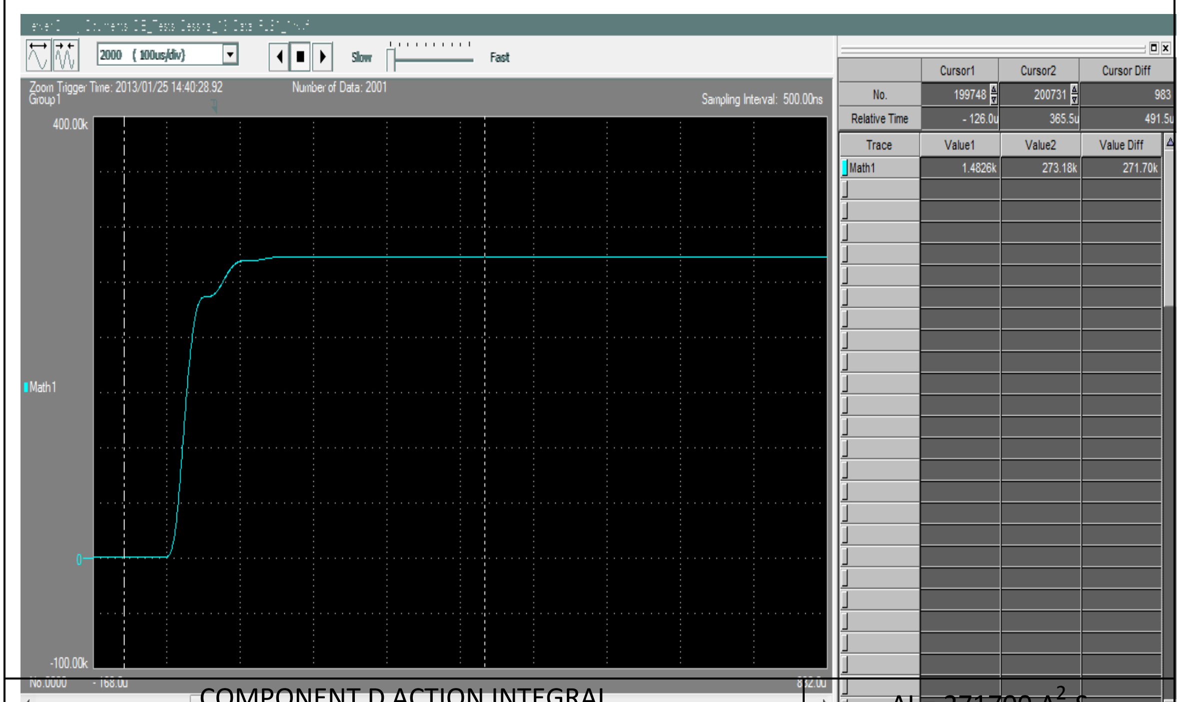


COMPONENT C* CHARGE TRANSFER	18.5 Coulombs

CALIBRATION

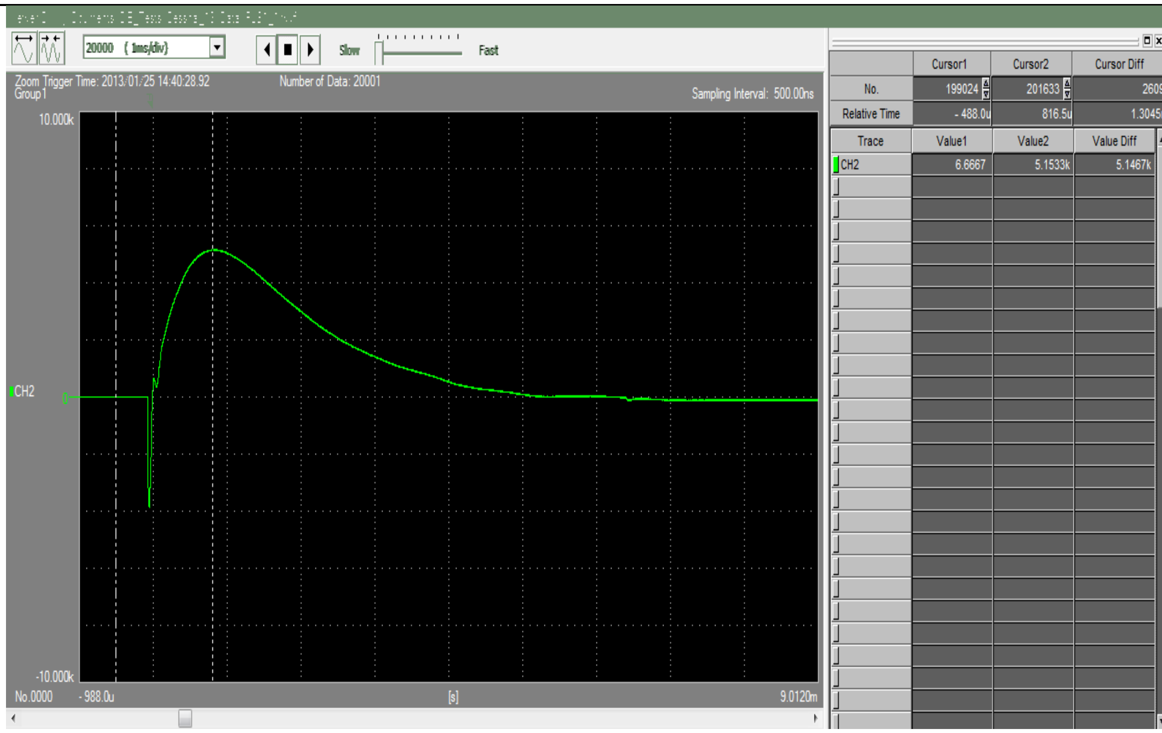


HIGH CURRENT – COMPONENT D	I_P = 94.0 KA	100 uS / Div

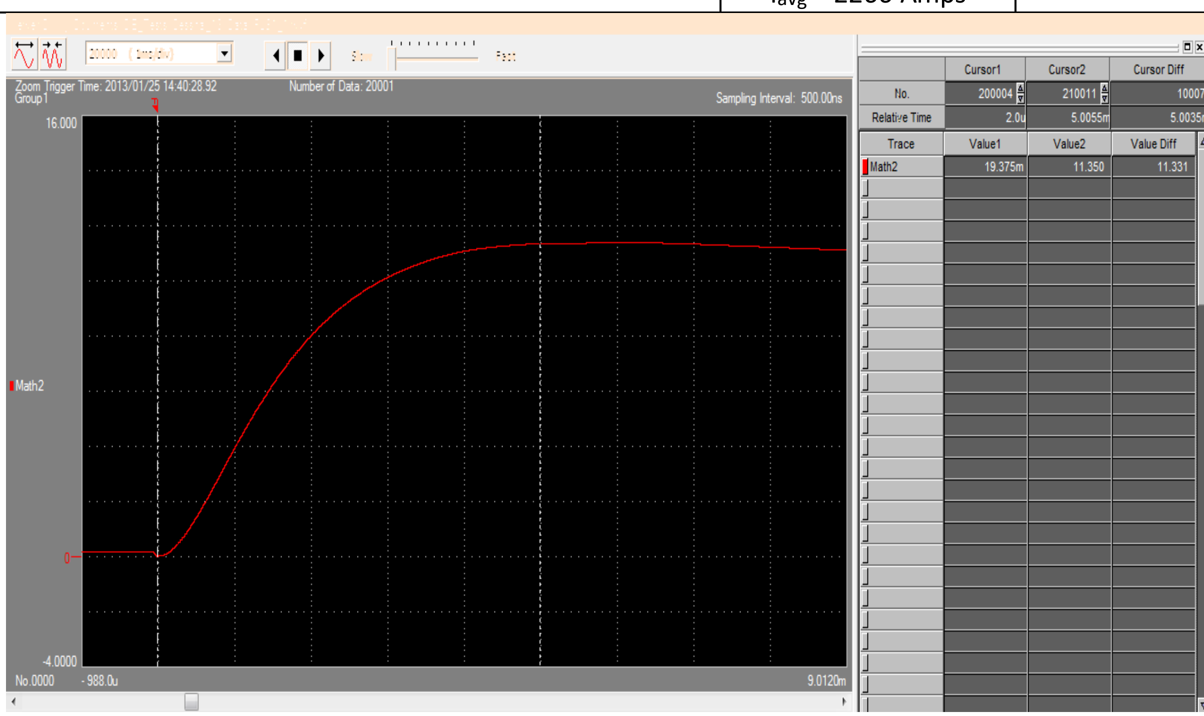


COMPONENT D ACTION INTEGRAL	AI = 271700 A^2-S

Panel: FLS1 – First Strike



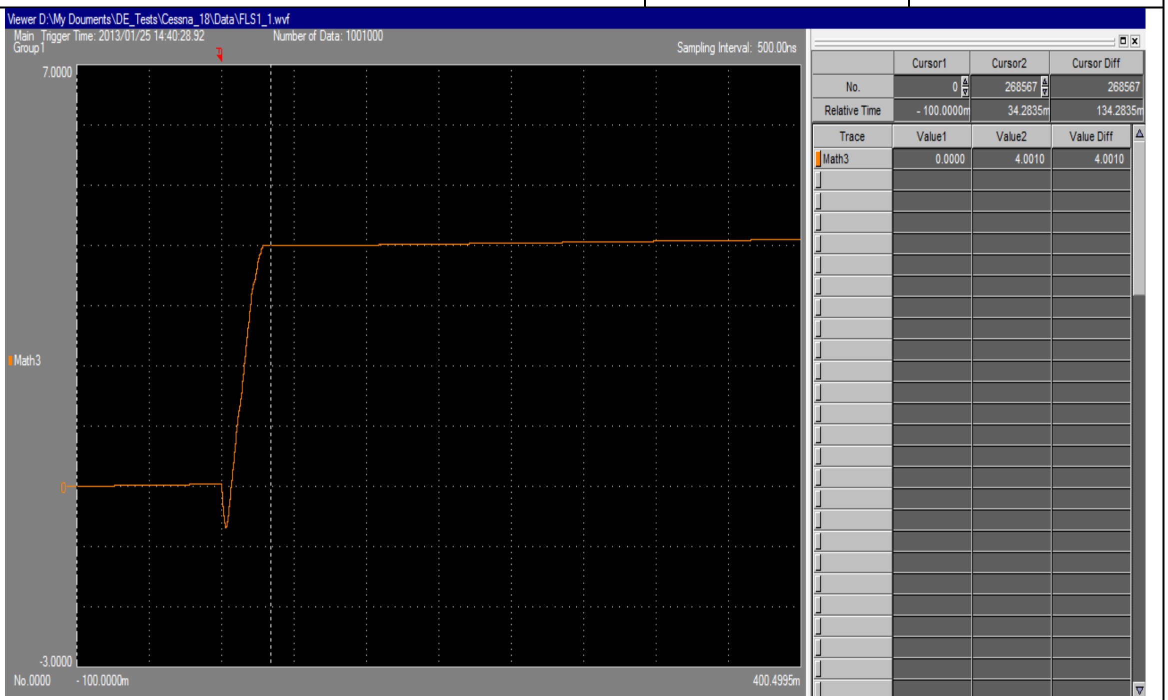
HIGH CURRENT – COMPONENT B	I_P = 5147 Amps I_{avg} = 2266 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.331 Coulombs

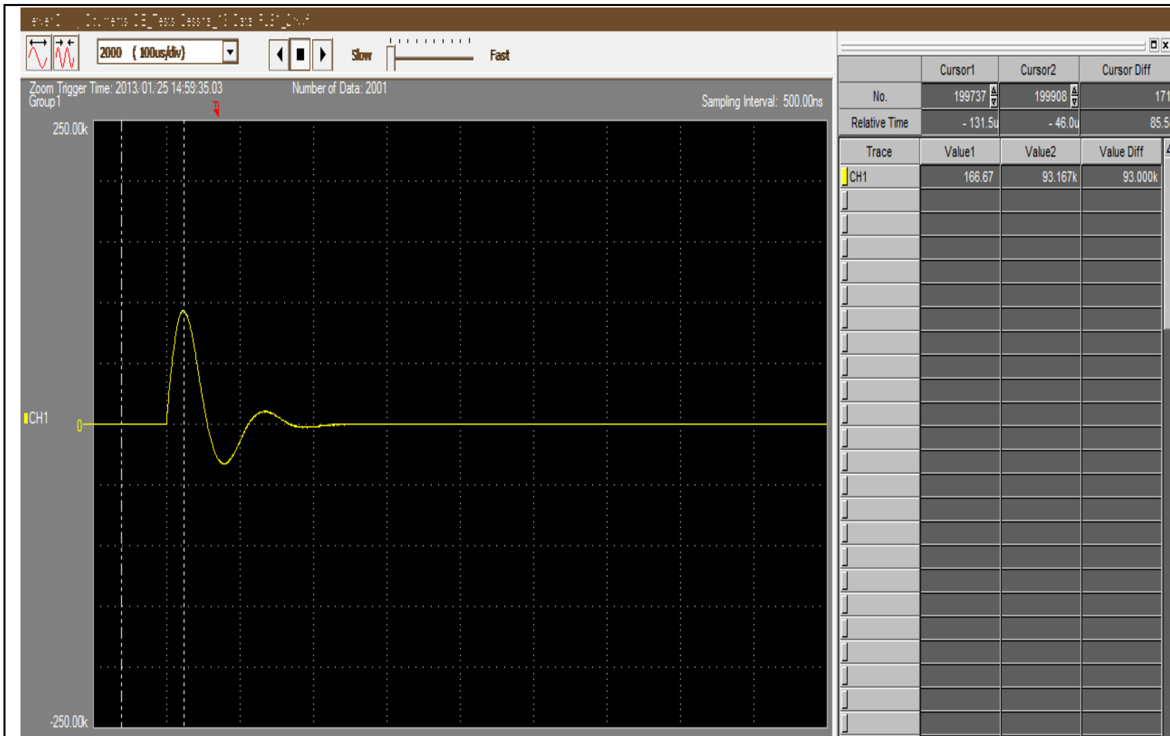
Panel: FLS1 – First Strike

HIGH CURRENT – COMPONENT C*	I_P = 267 Amps	50 mS / Div

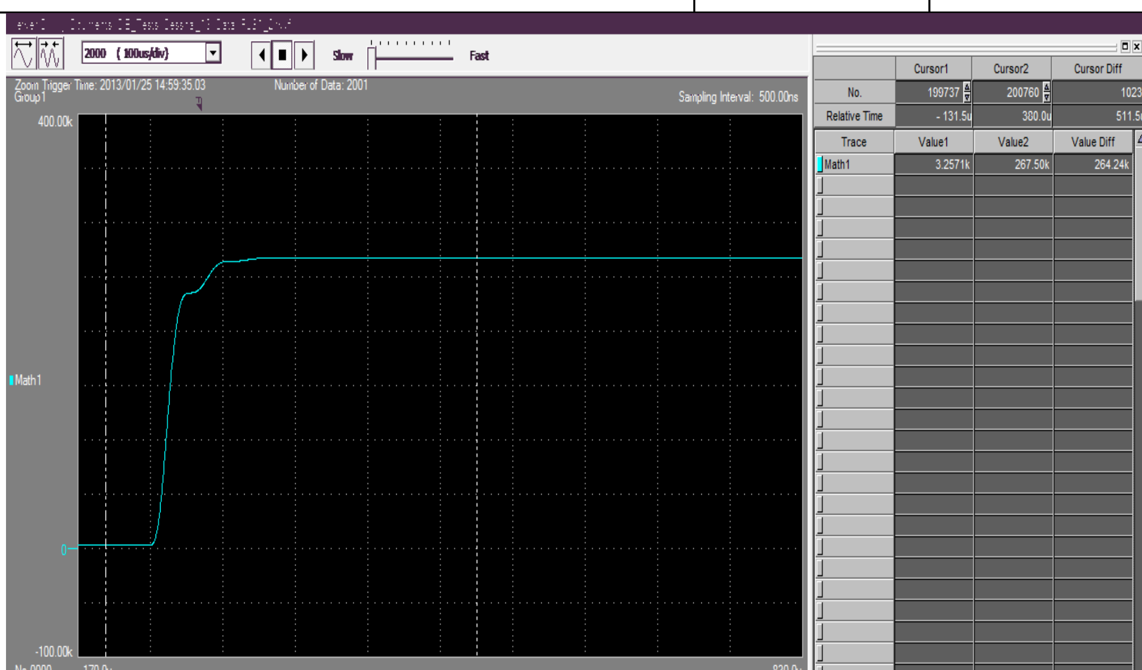


COMPONENT C* CHARGE TRANSFER	4.0 Coulombs

Panel: FLS1 – First Strike

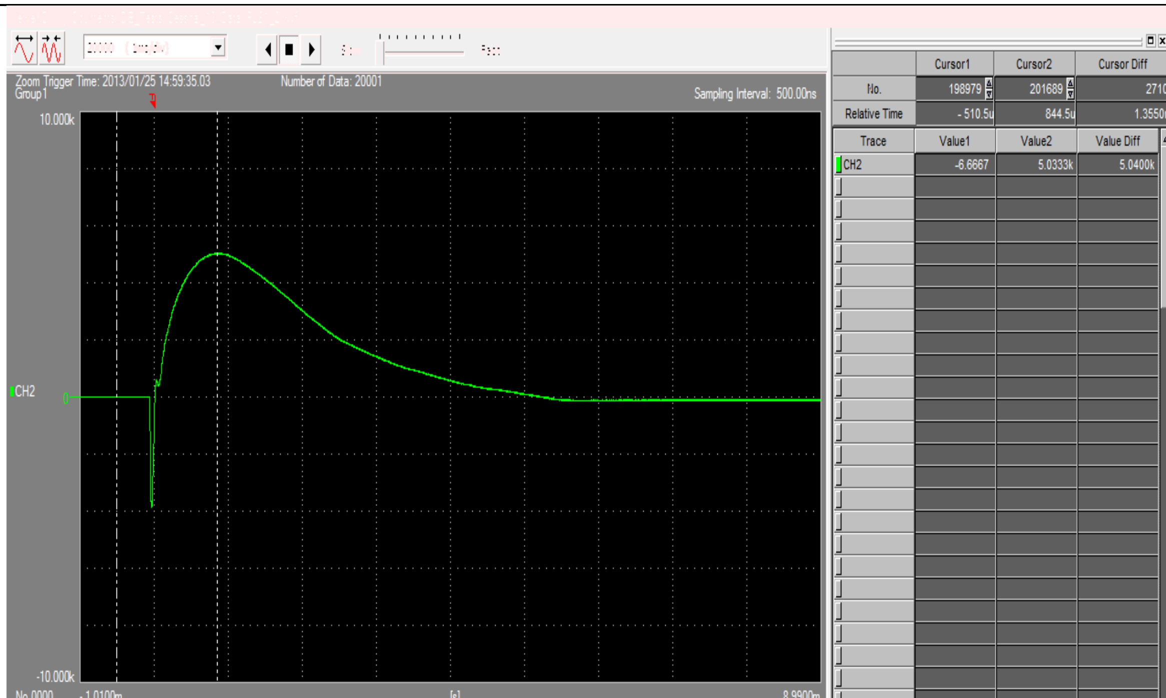


HIGH CURRENT – COMPONENT D	I_P = 93.0 KA	100 uS / Div

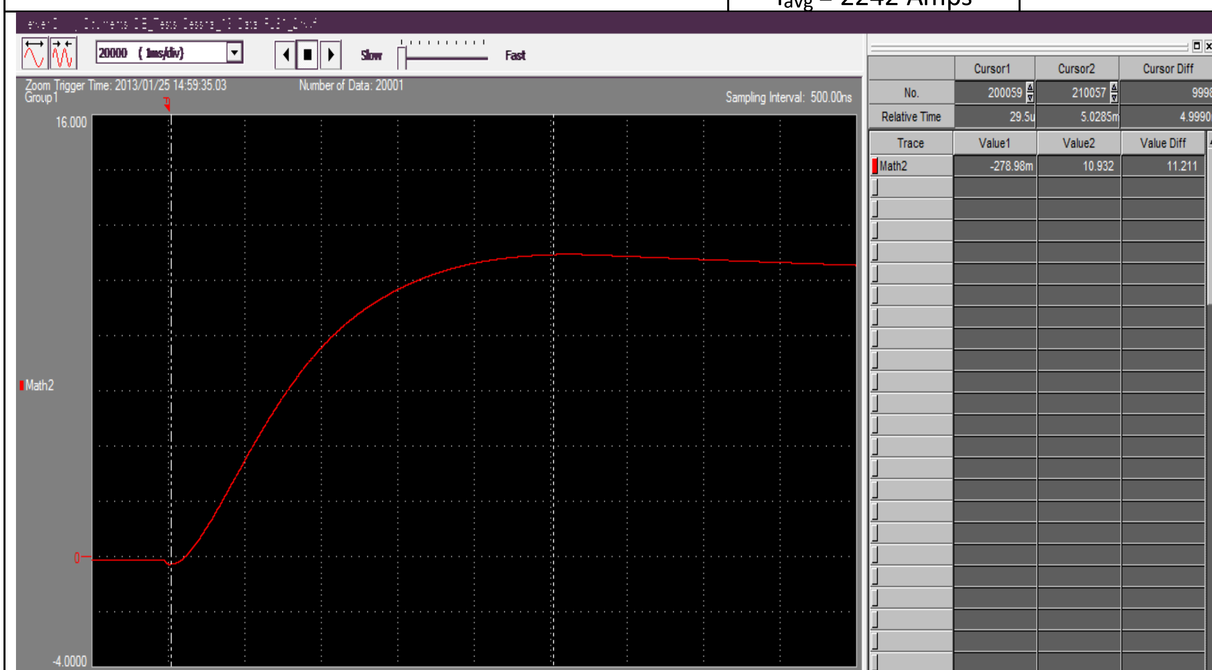


COMPONENT D ACTION INTEGRAL	AI = 264240 A^2-S

Panel: FLS1 – Second Strike

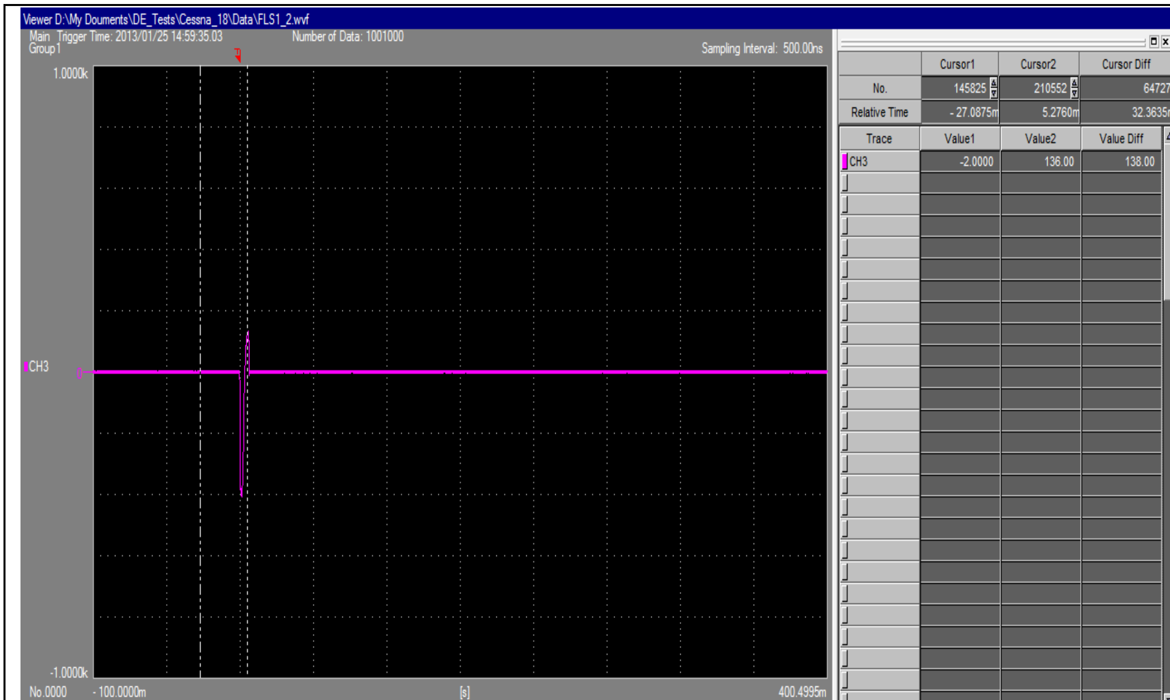


HIGH CURRENT – COMPONENT B	I_P = 5040 Amps I_{avg} = 2242 Amps	1 mS / Div

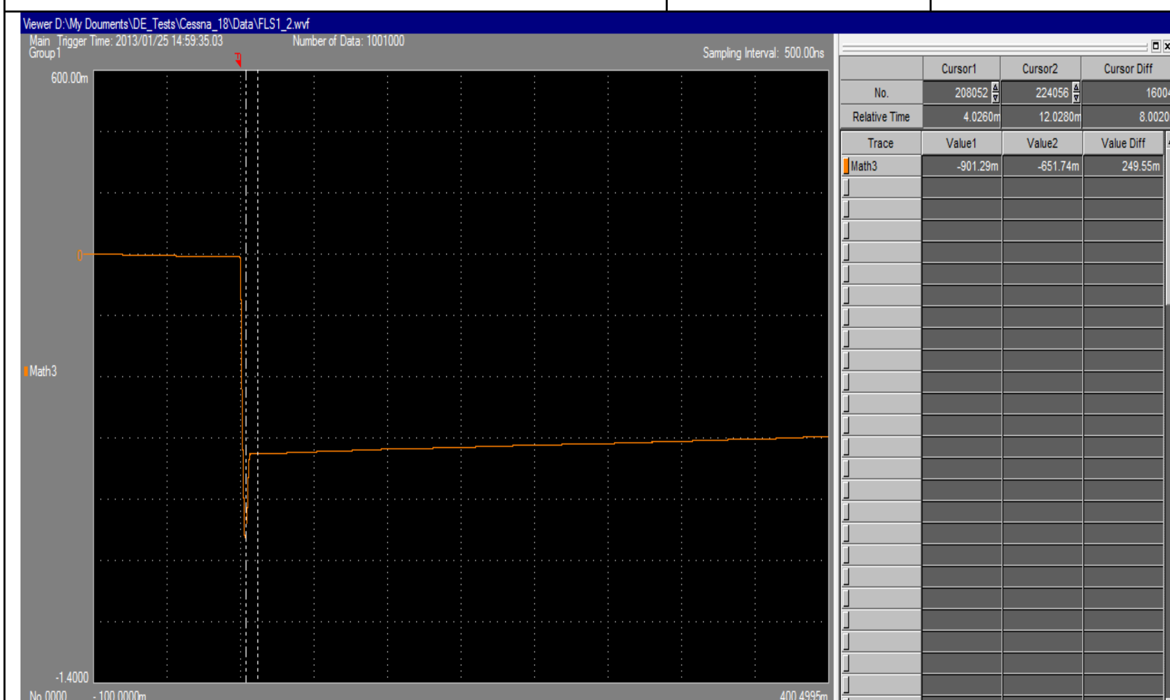


COMPONENT B CHARGE TRANSFER	11.211 Coulombs

Panel: FLS1 – Second Strike

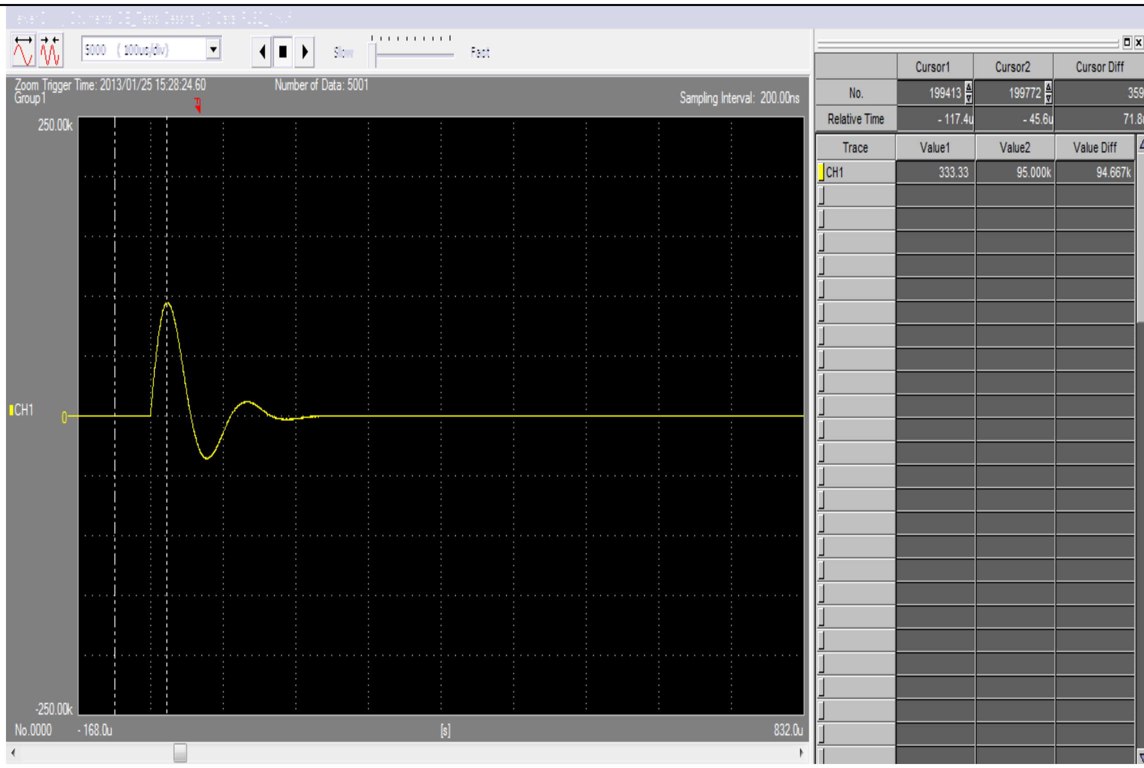


HIGH CURRENT – COMPONENT C*	I_P = 138 Amps	50 mS / Div

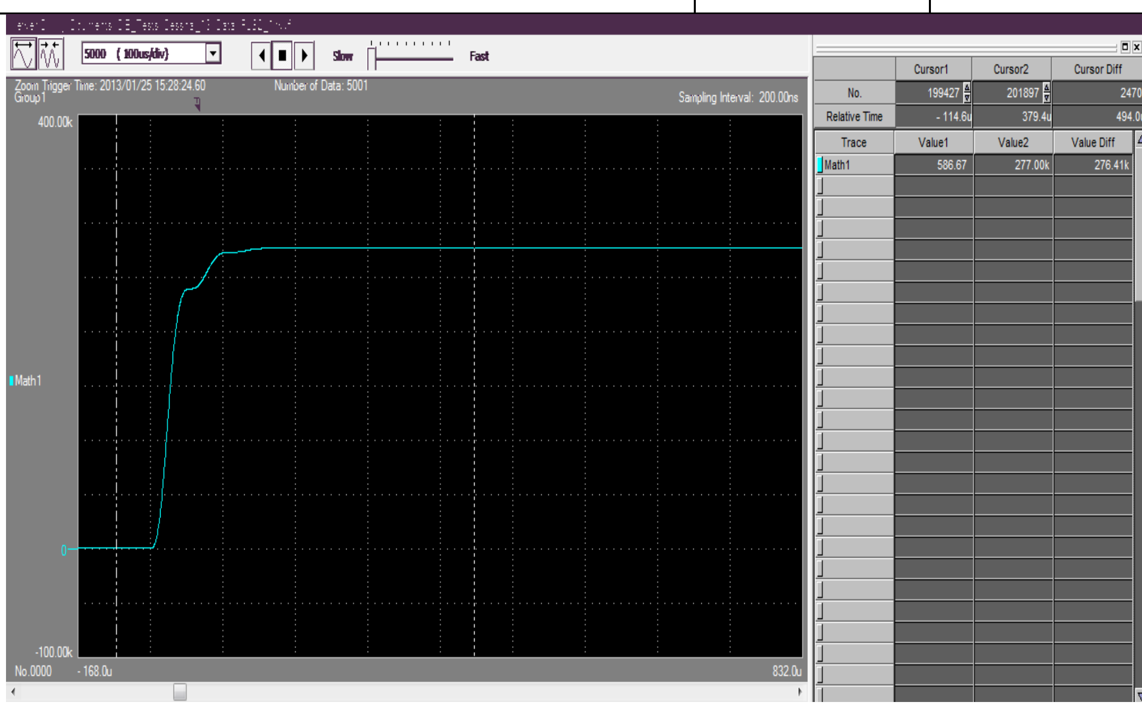


COMPONENT C* CHARGE TRANSFER	0.25 Coulombs

Panel: FLS1 – Second Strike

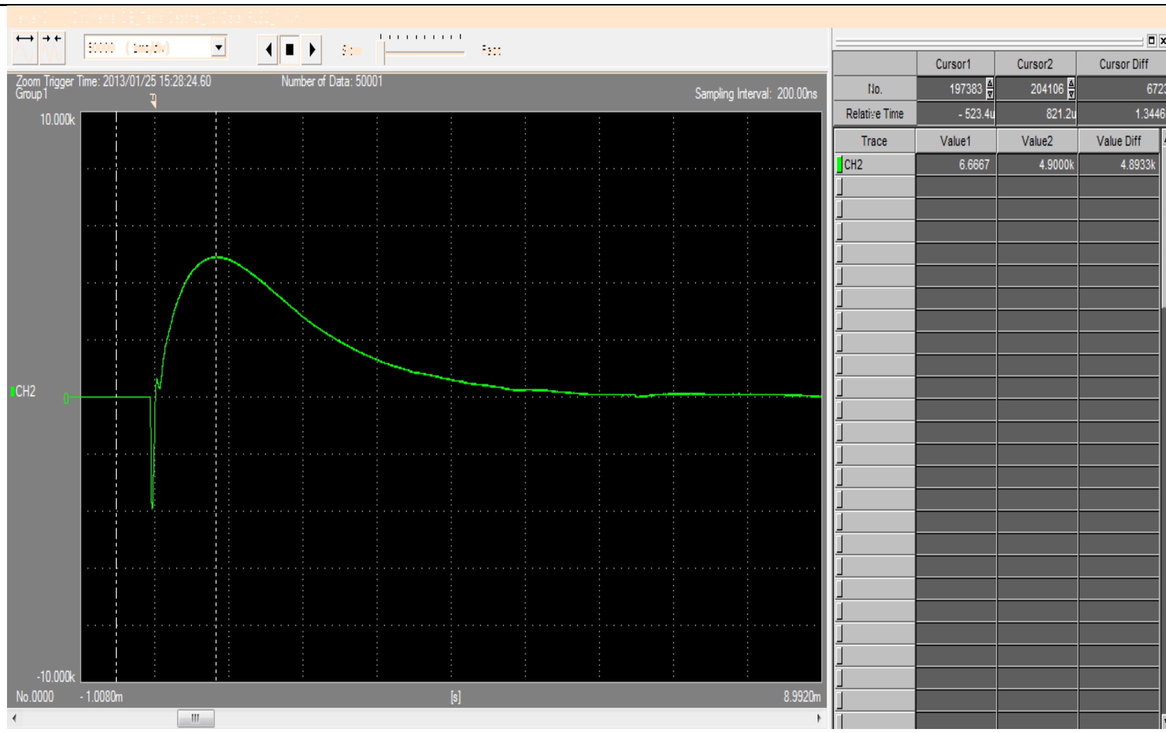


HIGH CURRENT – COMPONENT D	I_P = 94.7 KA	100 uS / Div

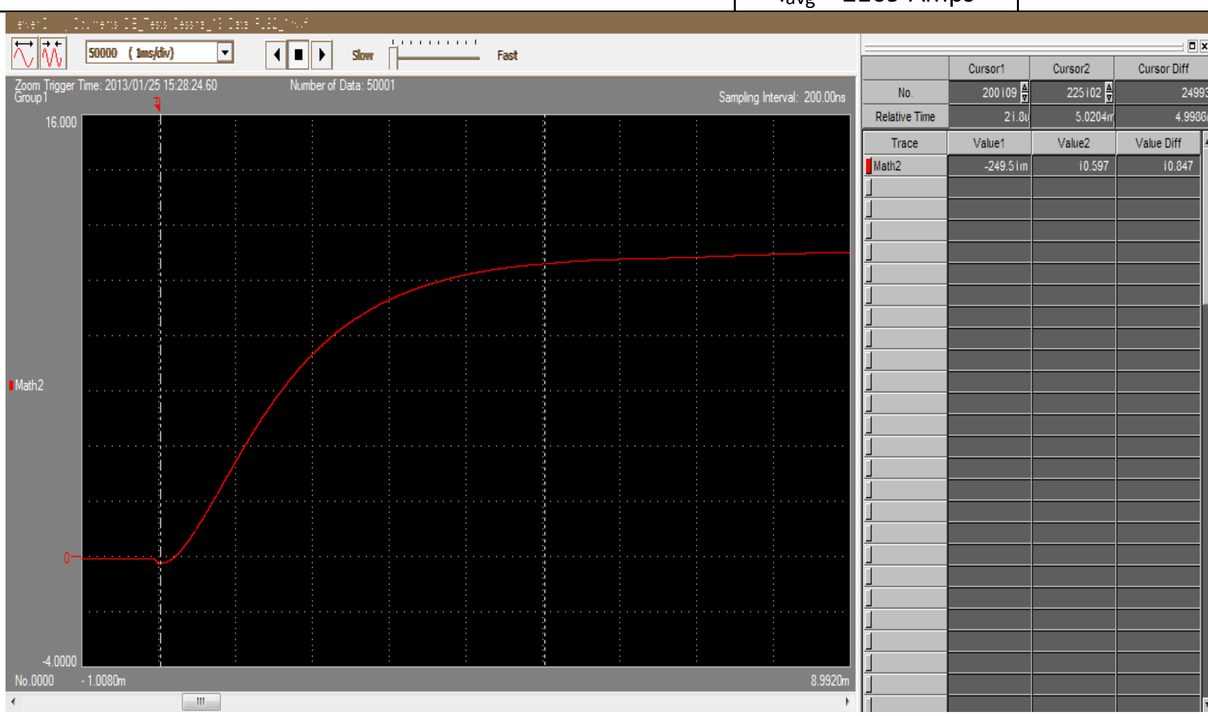


COMPONENT D ACTION INTEGRAL	AI = 276410 A^2-S

Panel: FLS2 – First Strike

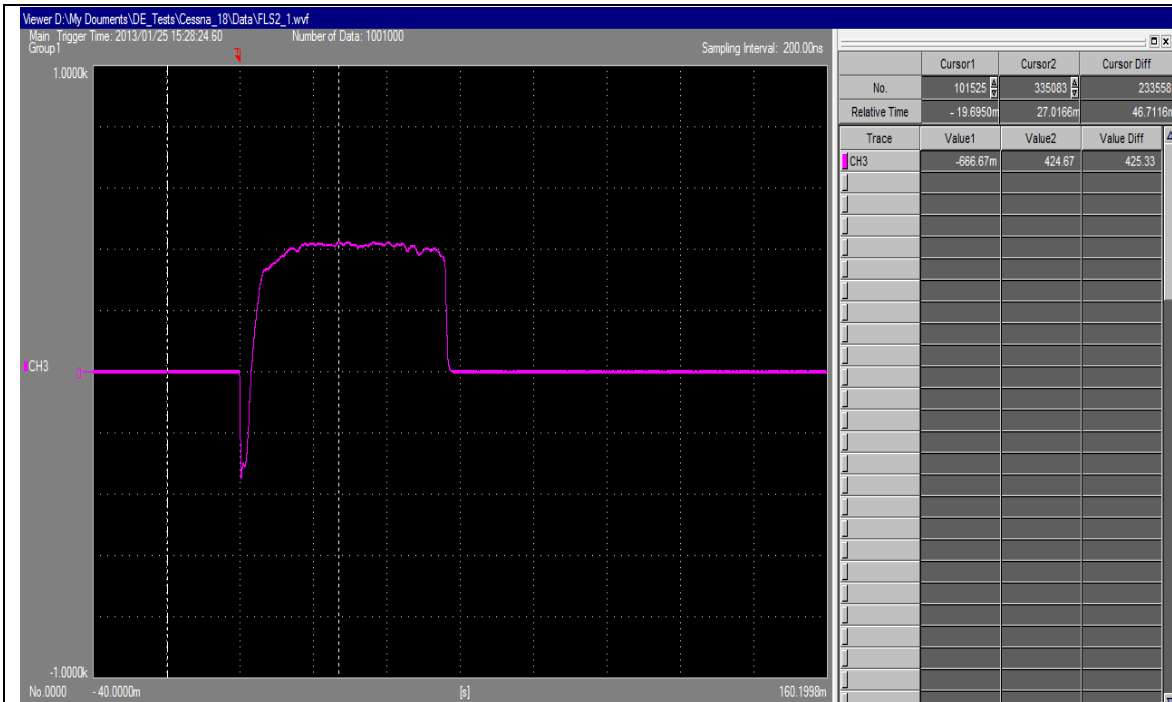


HIGH CURRENT – COMPONENT B	I_P = 4893 Amps I_{avg} = 2169 Amps	1 mS / Div

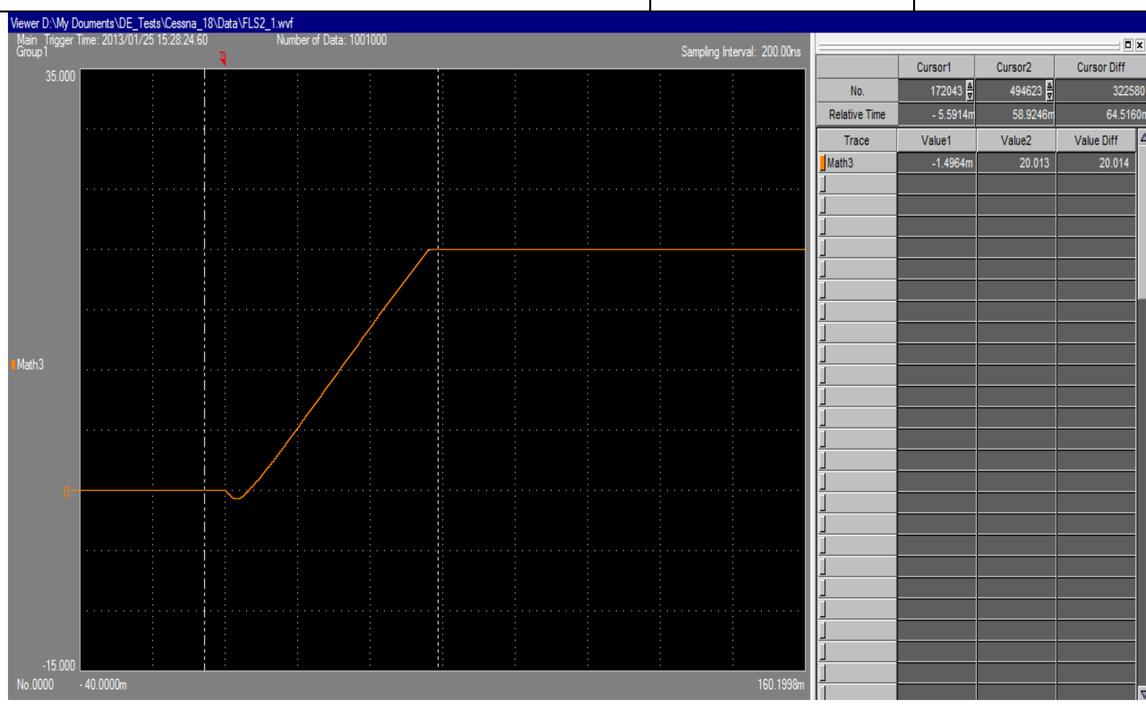


COMPONENT B CHARGE TRANSFER	10.847 Coulombs

Panel: FLS2 – First Strike

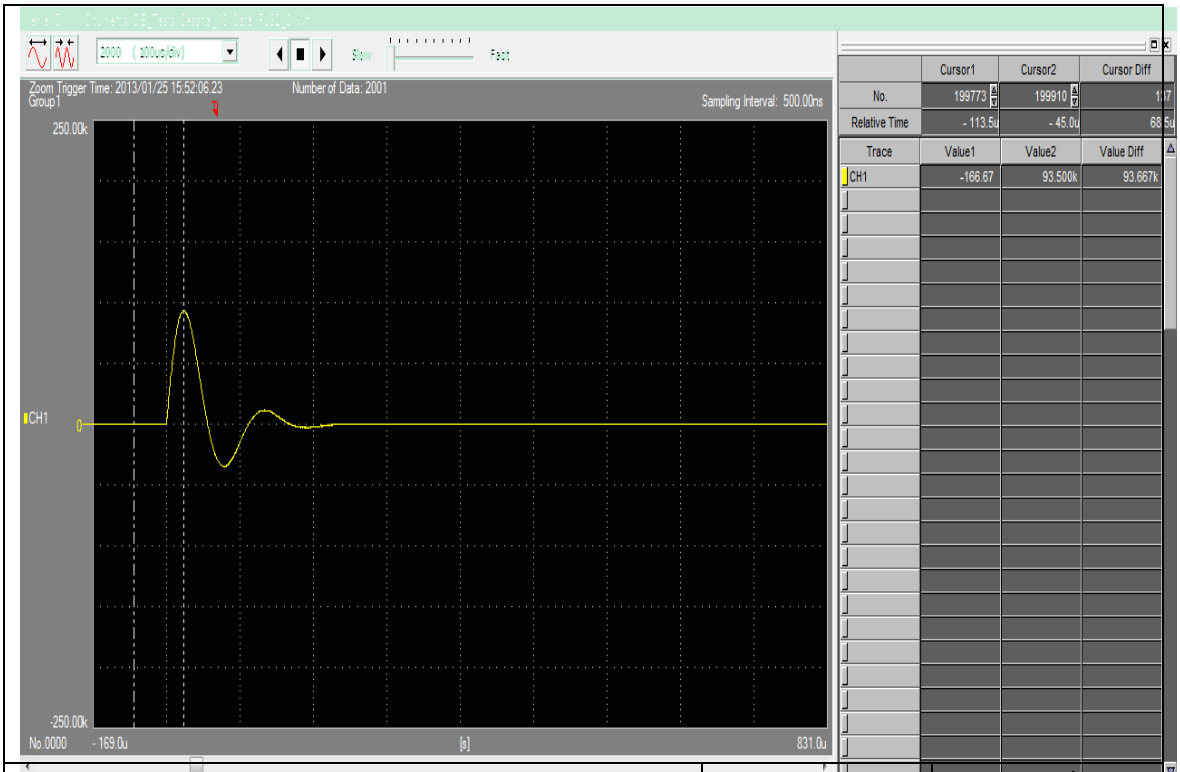


HIGH CURRENT – COMPONENT C*	I_P = 425 Amps	20 mS / Div

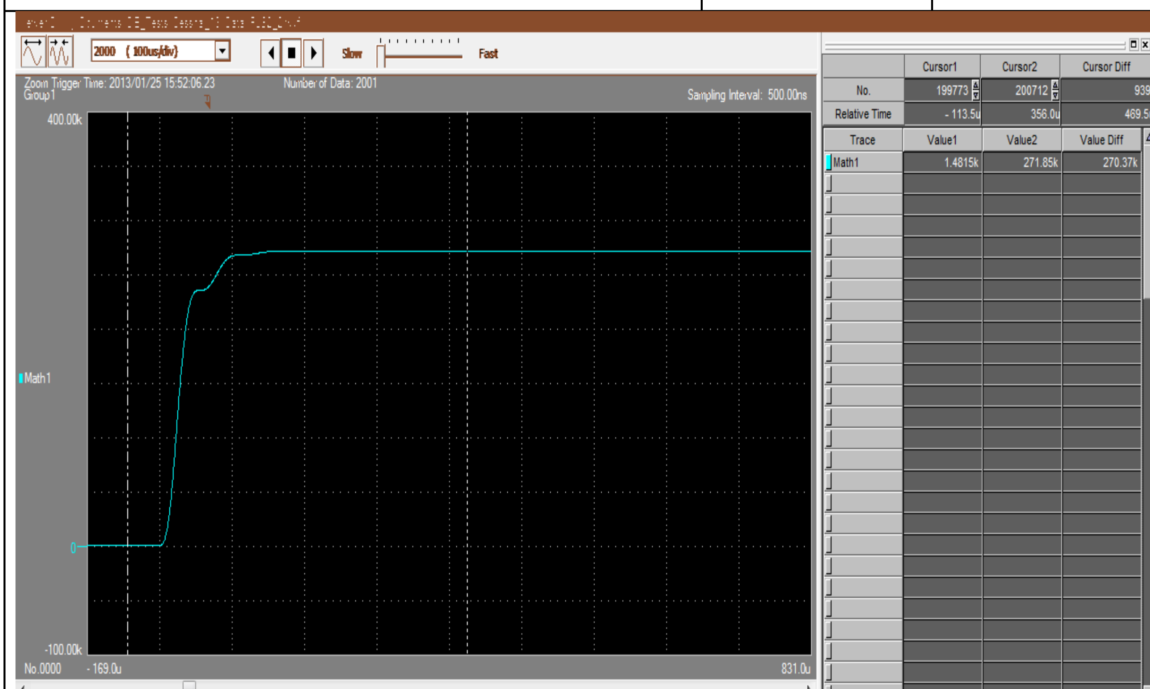


COMPONENT C* CHARGE TRANSFER	20.0 Coulombs

Panel: FLS2 – First Strike

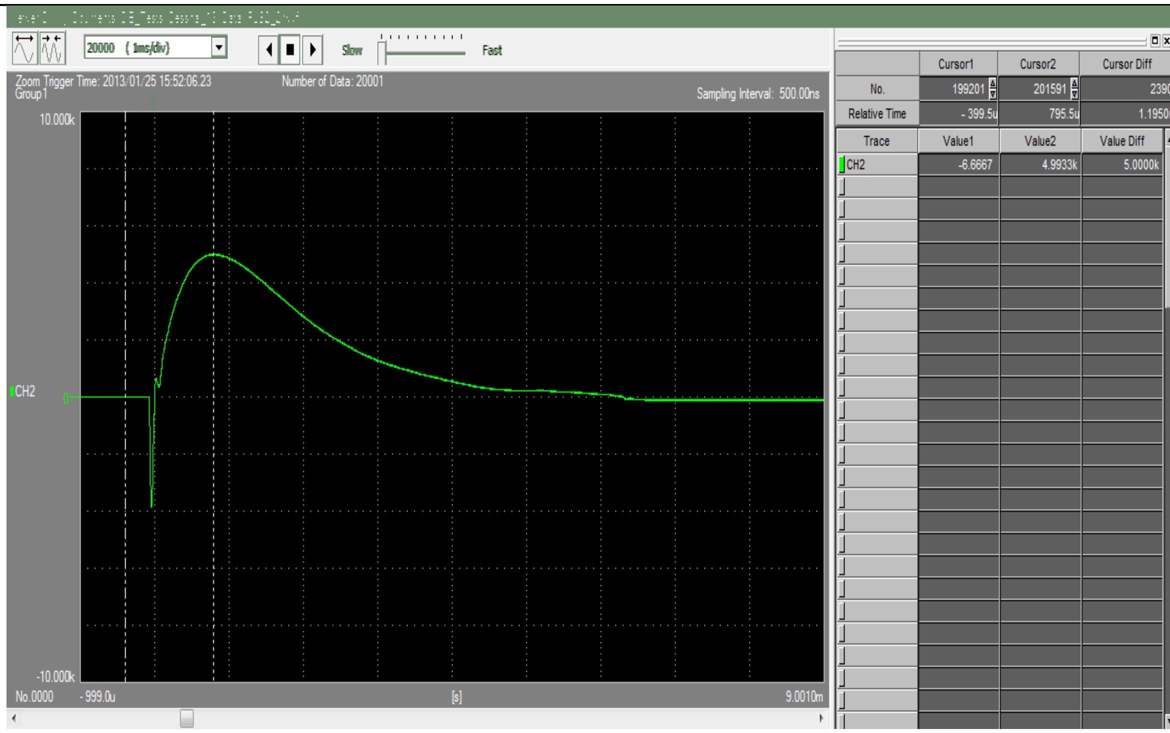


HIGH CURRENT – COMPONENT D	I_P = 93.7 KA	100 uS / Div

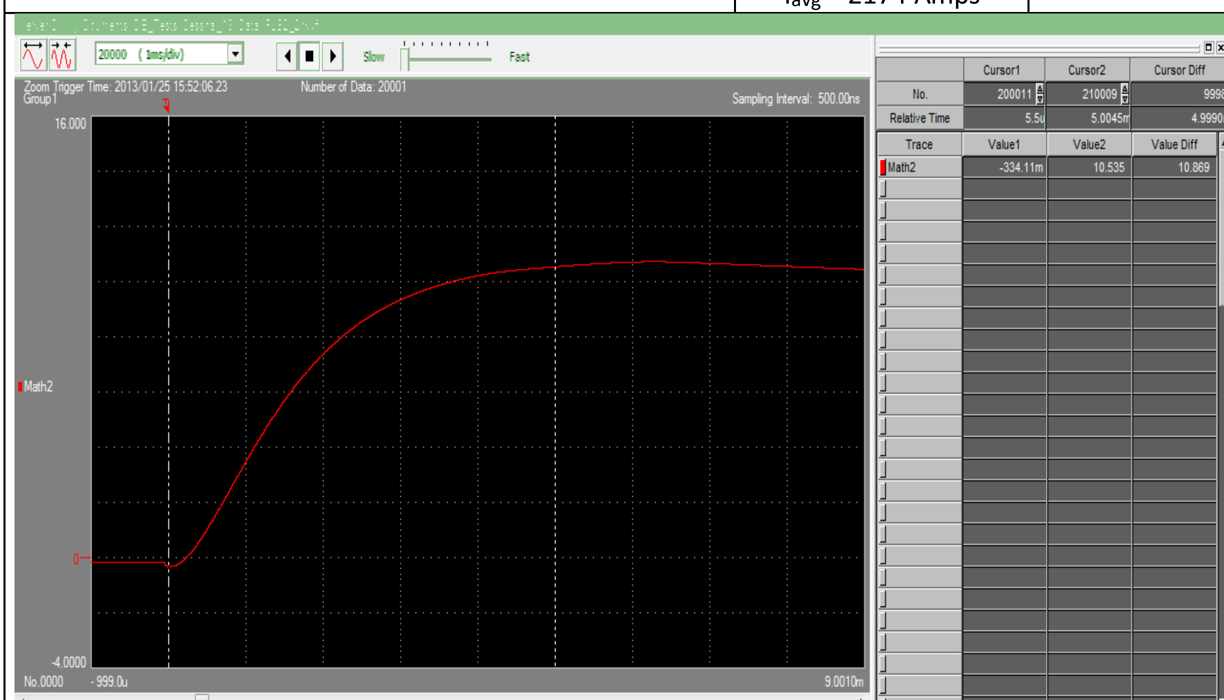


COMPONENT D ACTION INTEGRAL	AI = 270370 A^2-S

Panel: FLS2 – Second Strike

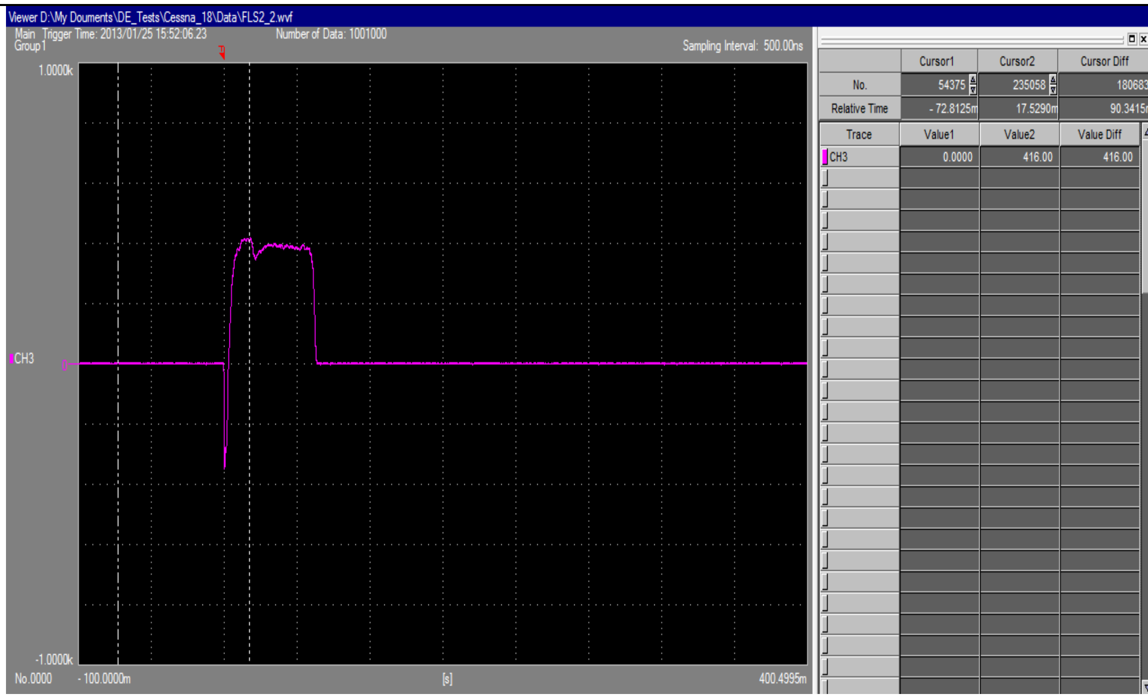


HIGH CURRENT – COMPONENT B	I_P = 5000 Amps I_{avg} = 2174 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.869 Coulombs

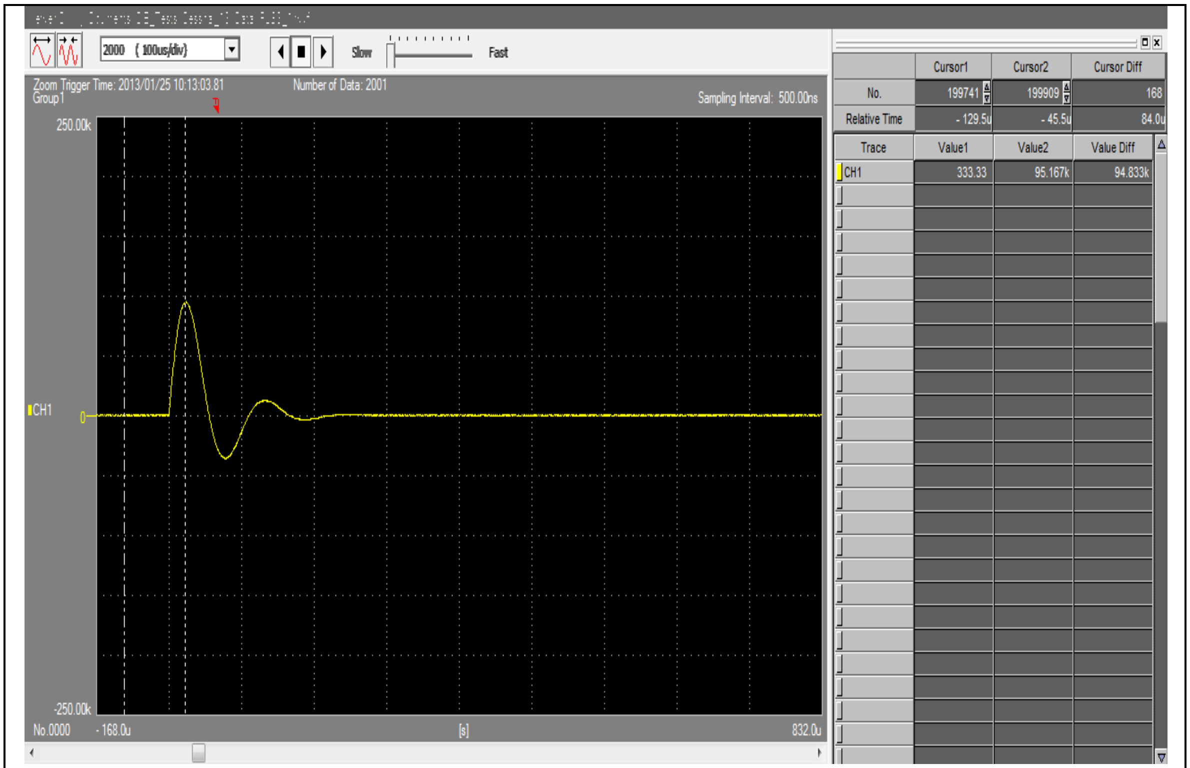
Panel: FLS2 – Second Strike



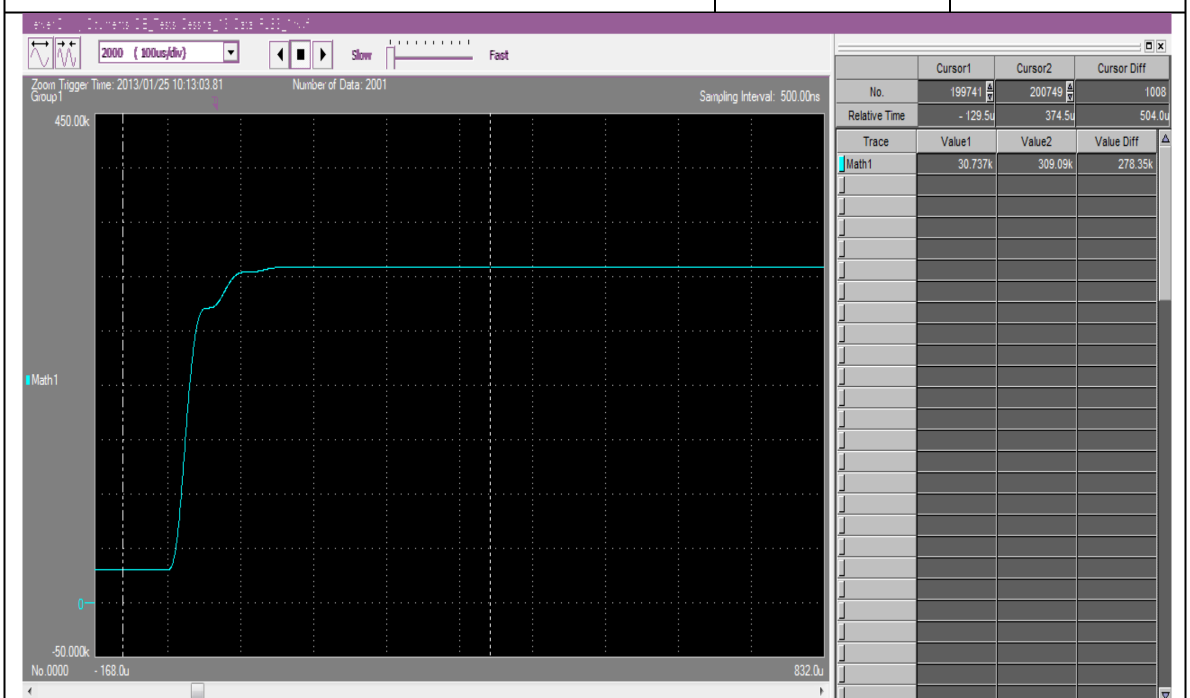
HIGH CURRENT – COMPONENT C*	I_P = 416 Amps	50 mS / Div

COMPONENT C* CHARGE TRANSFER	21.4 Coulombs

Panel: FLS2 – Second Strike

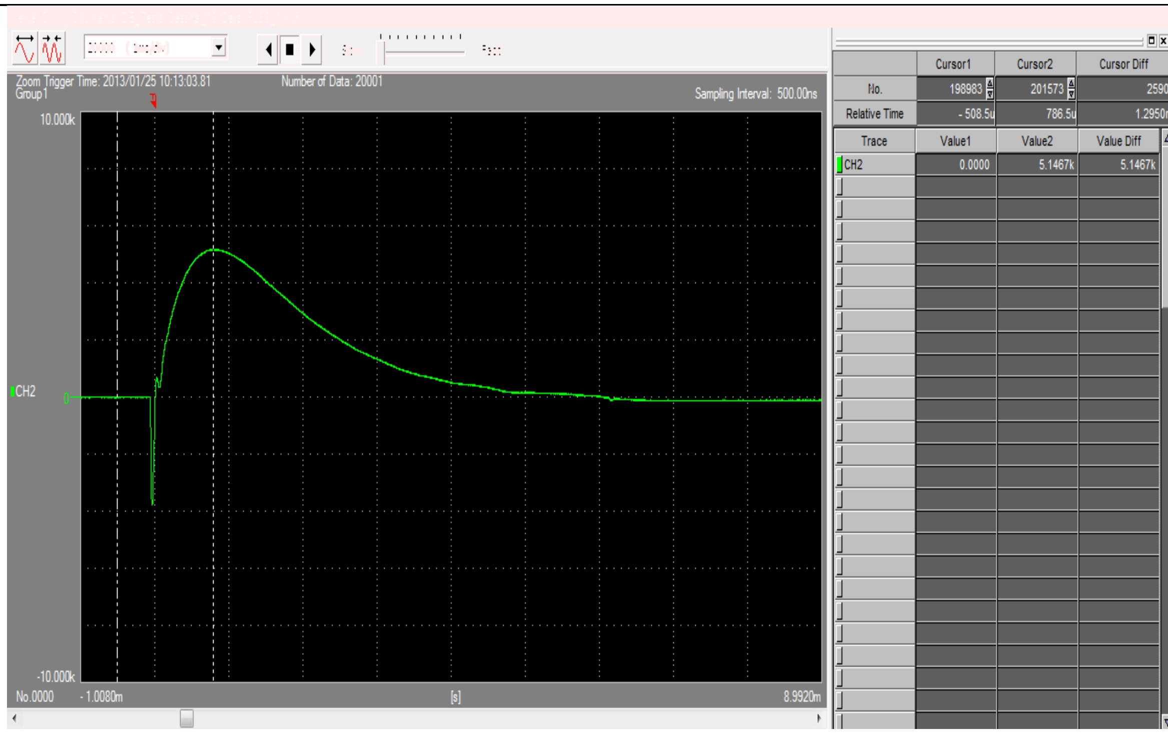


HIGH CURRENT – COMPONENT D	I_P = 94.8 KA	100 uS / Div

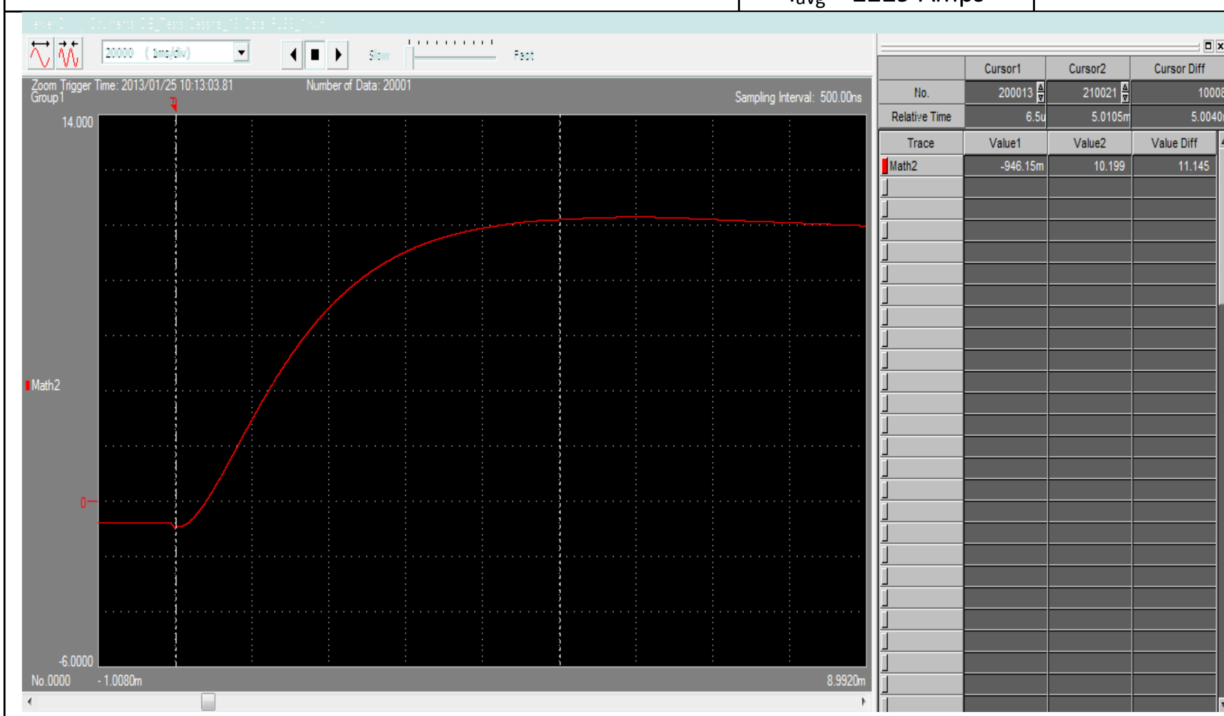


COMPONENT D ACTION INTEGRAL	AI = 278350 A^2-S

Panel: FLS3 – First Strike

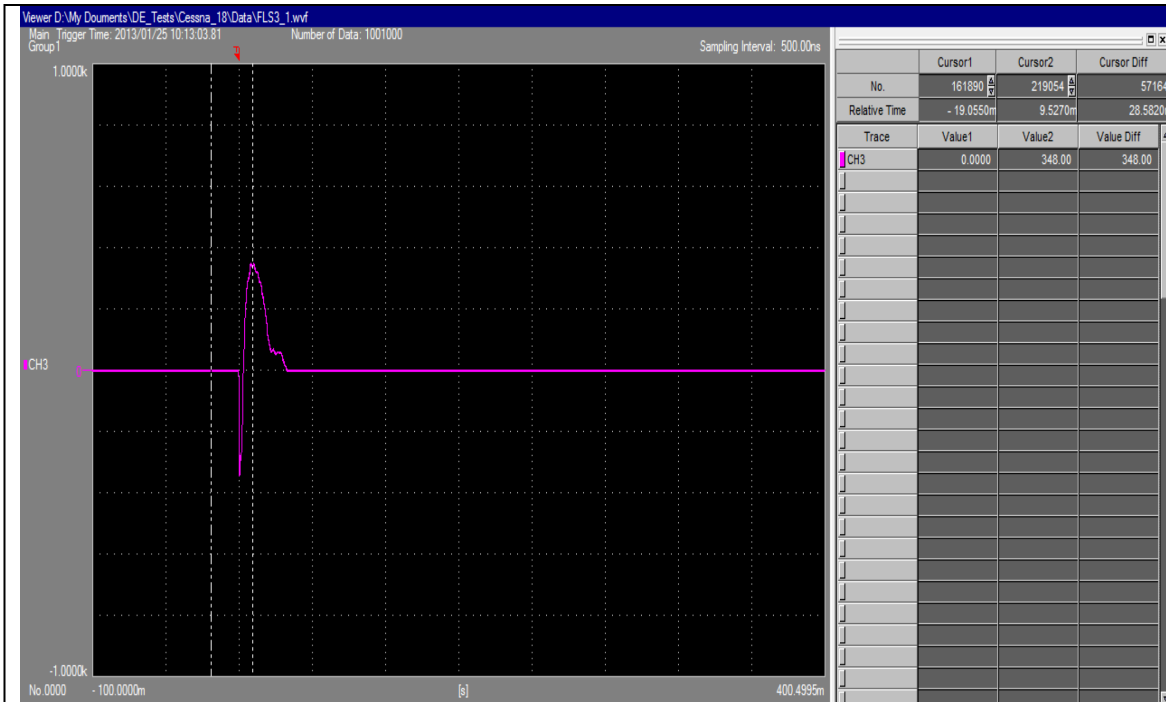


HIGH CURRENT – COMPONENT B	I_P = 5147 Amps I_{avg} = 2229 Amps	1 mS / Div

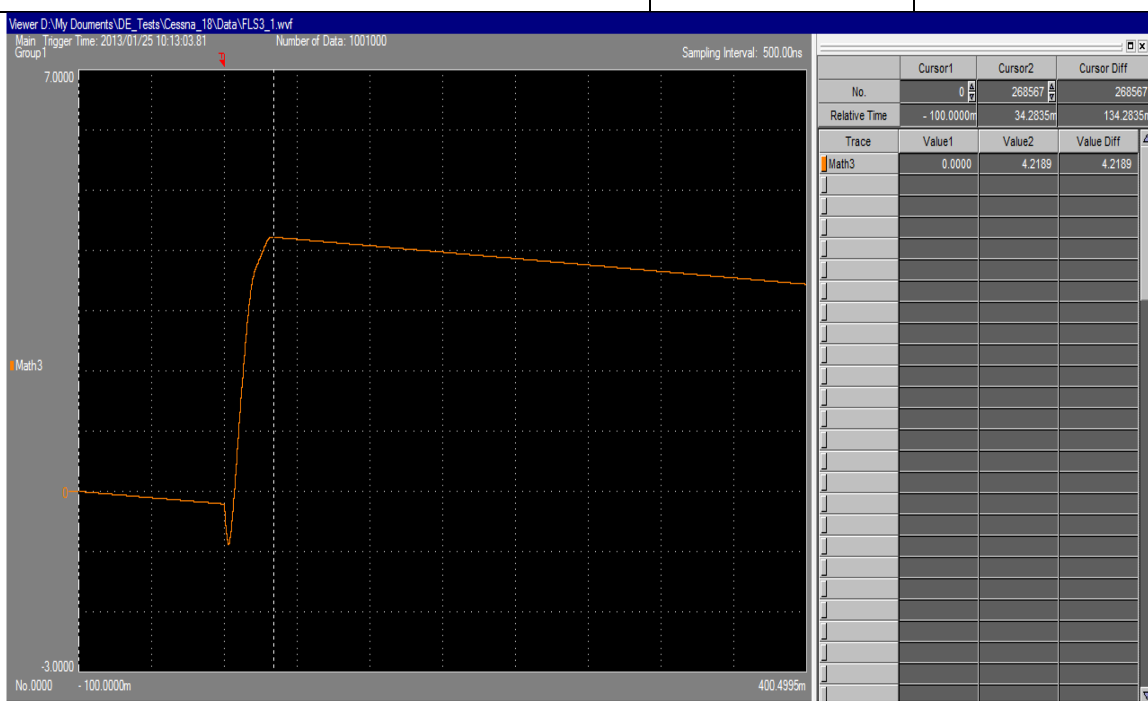


COMPONENT B CHARGE TRANSFER	11.145 Coulombs

Panel: FLS3 – First Strike

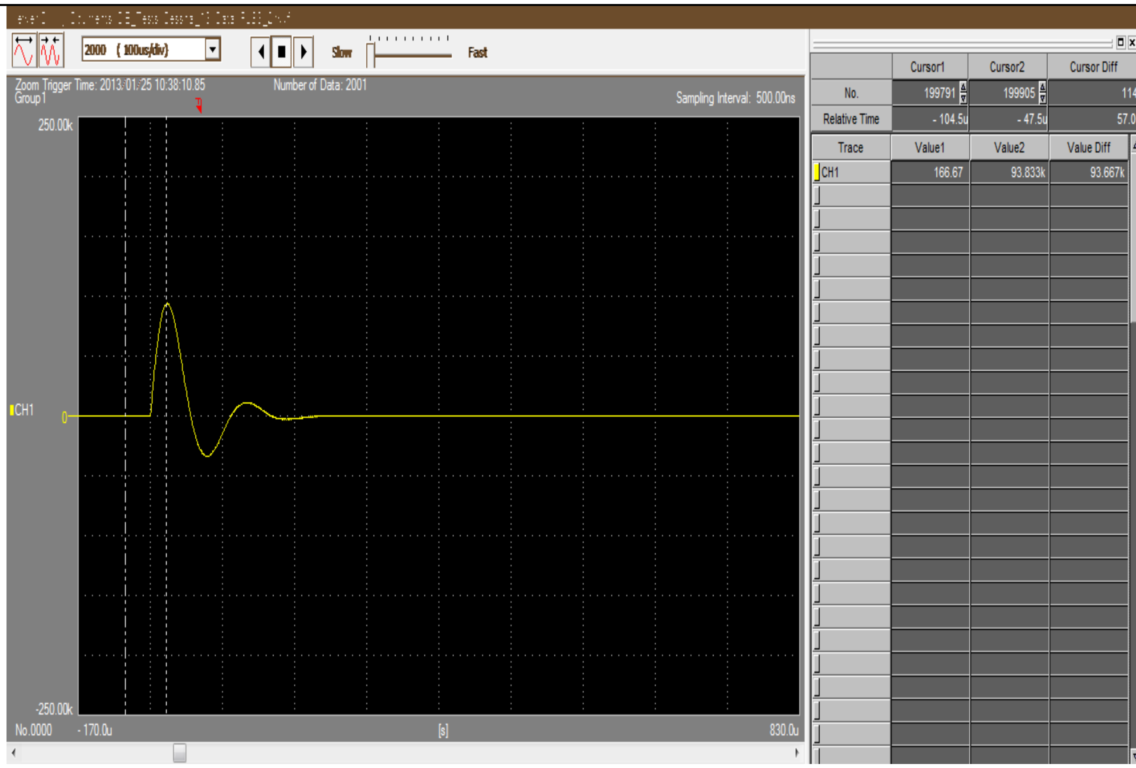


HIGH CURRENT – COMPONENT C*	I_P = 348 Amps	50 mS / Div

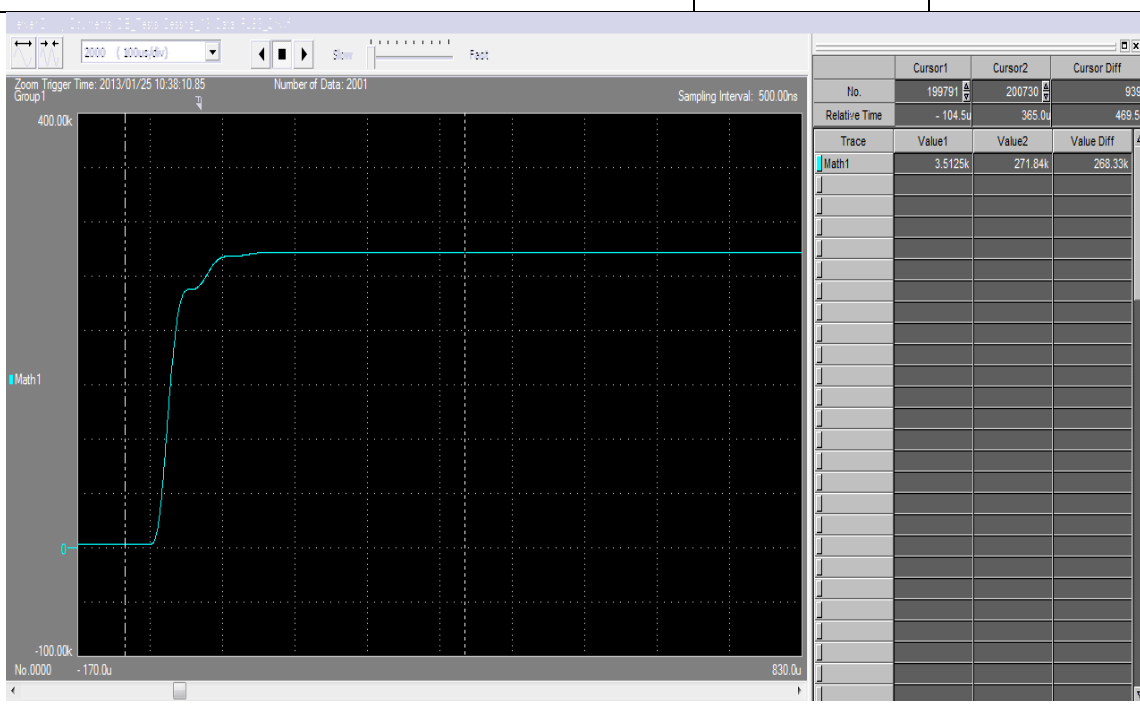


COMPONENT C* CHARGE TRANSFER	4.2 Coulombs

Panel: FLS3 – First Strike

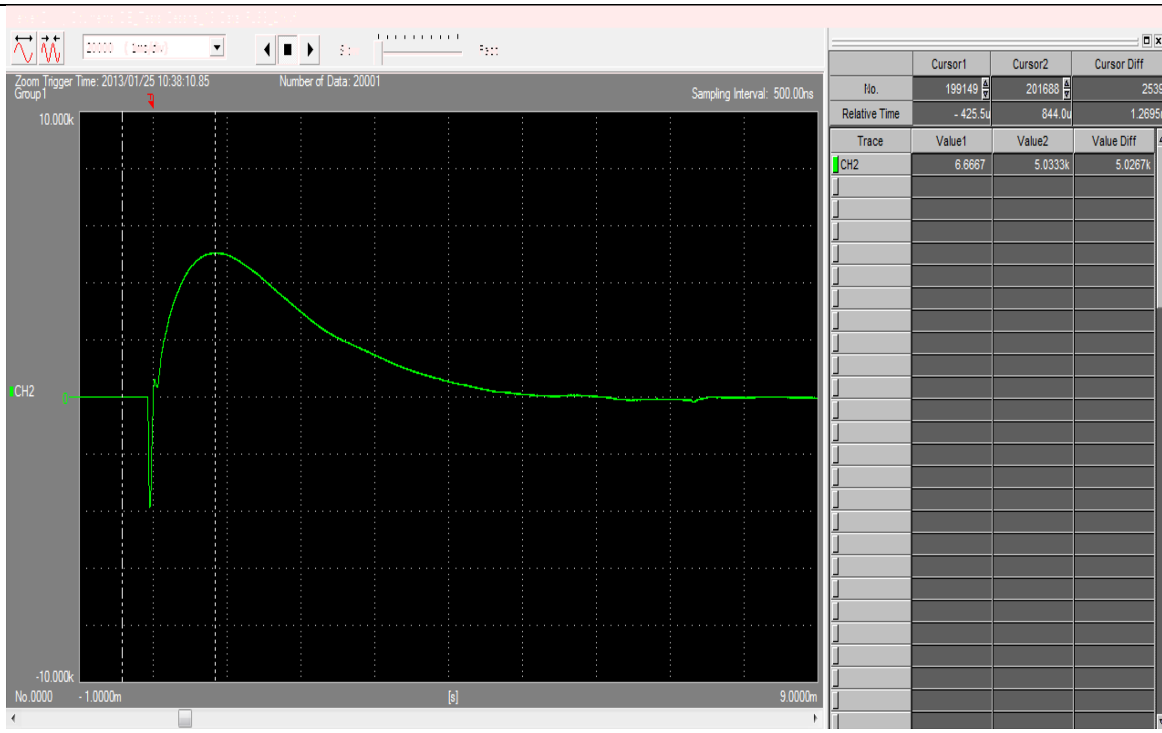


HIGH CURRENT – COMPONENT D	I_P = 93.7 KA	100 uS / Div

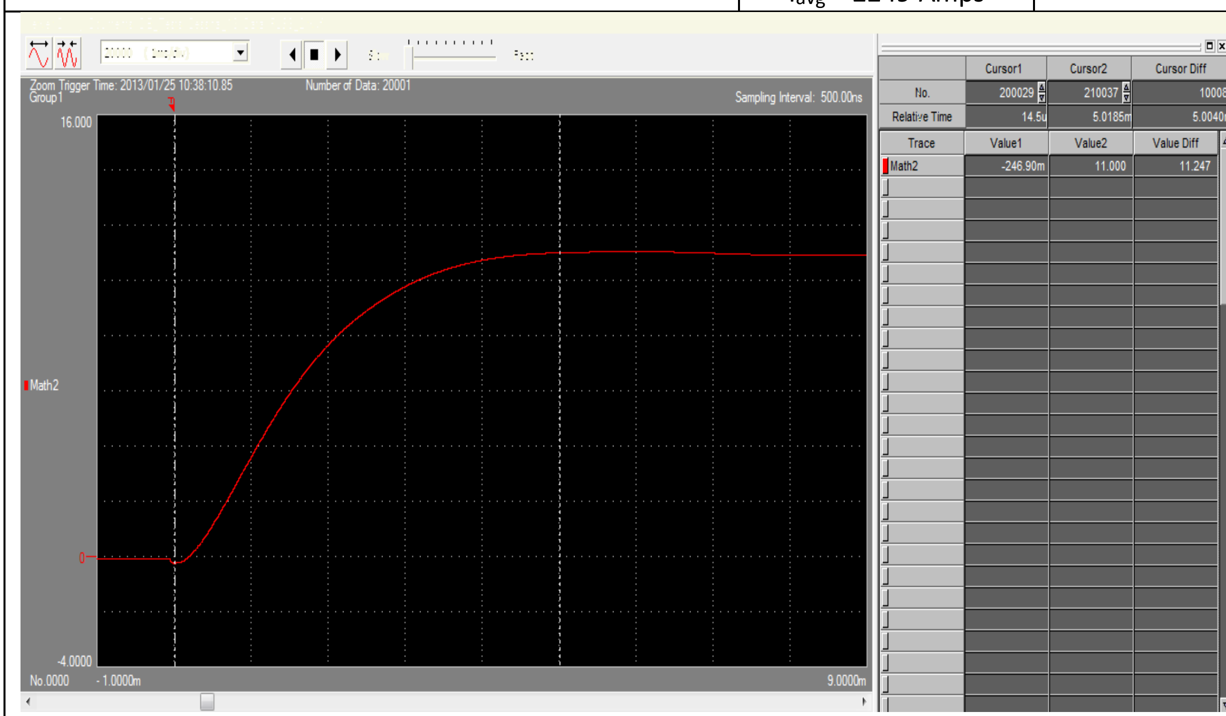


COMPONENT D ACTION INTEGRAL	AI = 268330 A^2-S

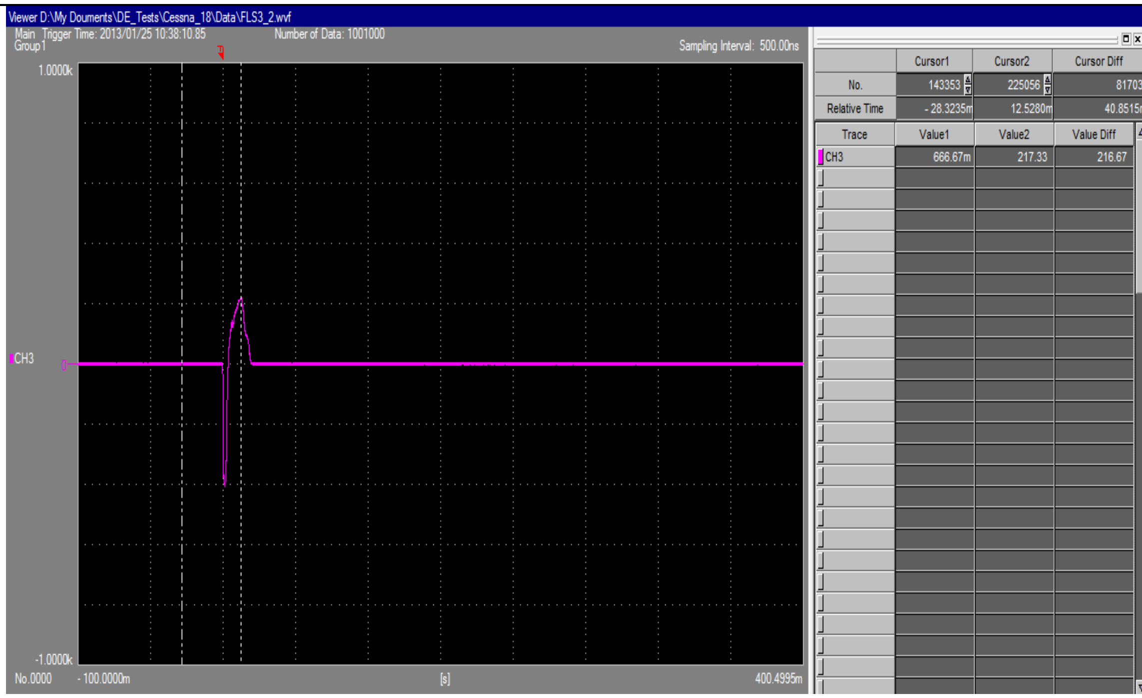
Panel: FLS3 – Second Strike



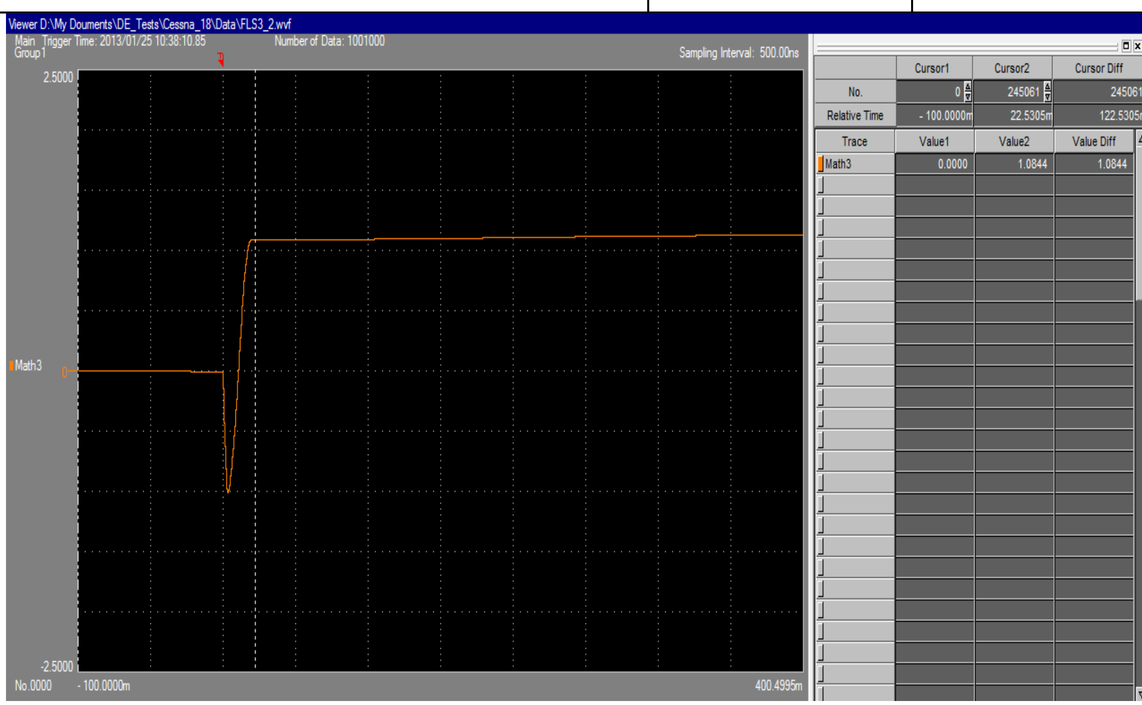
HIGH CURRENT – COMPONENT B	I_P = 5027 Amps I_{avg} = 2249 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	11.247 Coulombs
Panel: FLS3 – Second Strike	

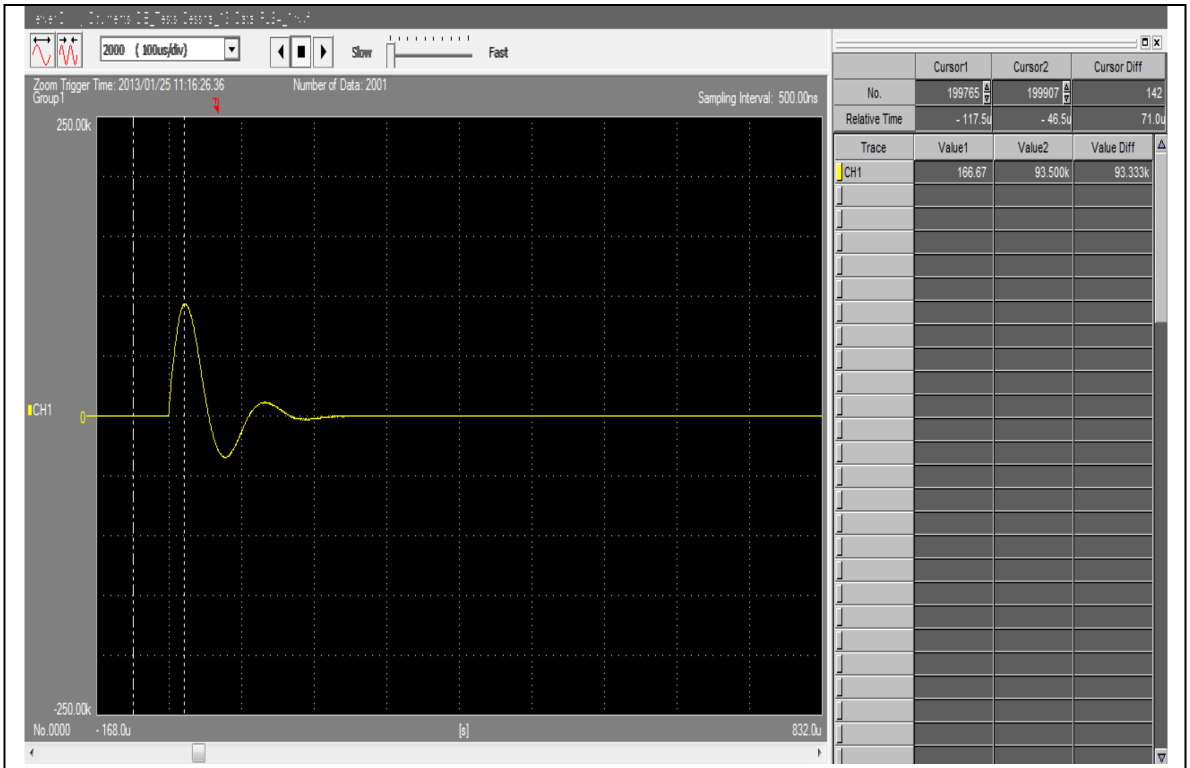


HIGH CURRENT – COMPONENT C*	I_P = 217 Amps	50 mS / Div

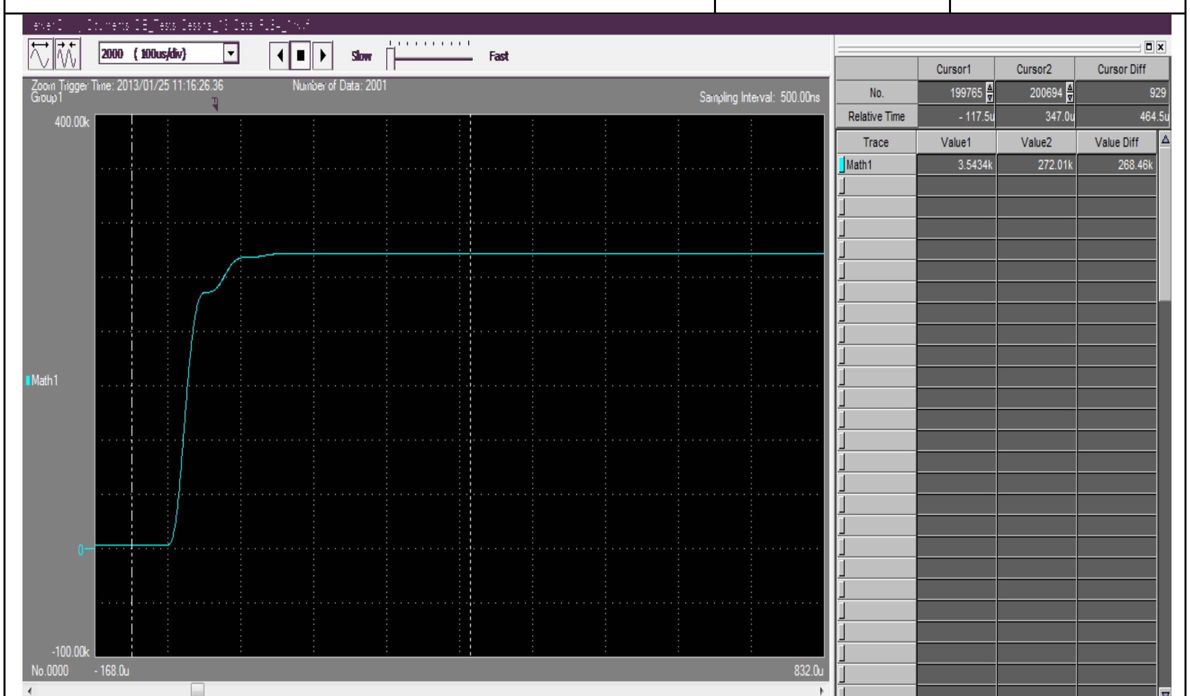


COMPONENT C* CHARGE TRANSFER	1.1 Coulombs

Panel: FLS3 – Second Strike

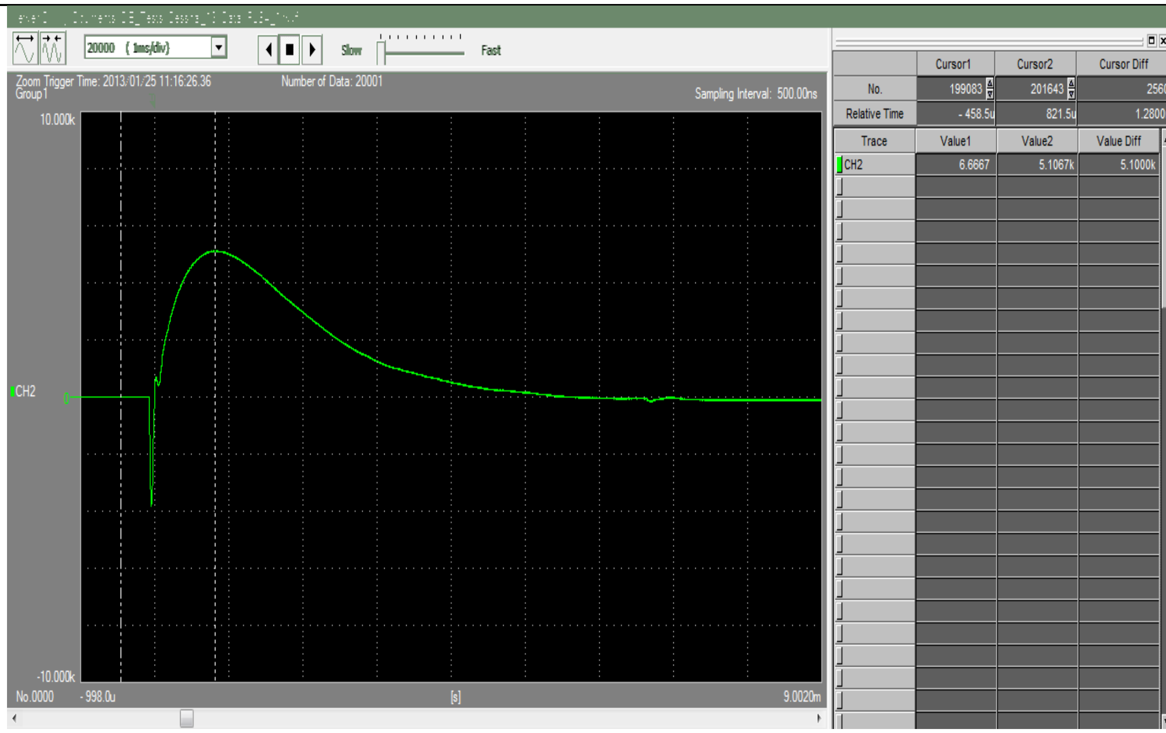


HIGH CURRENT – COMPONENT D	I_P = 93.3 KA	100 uS / Div

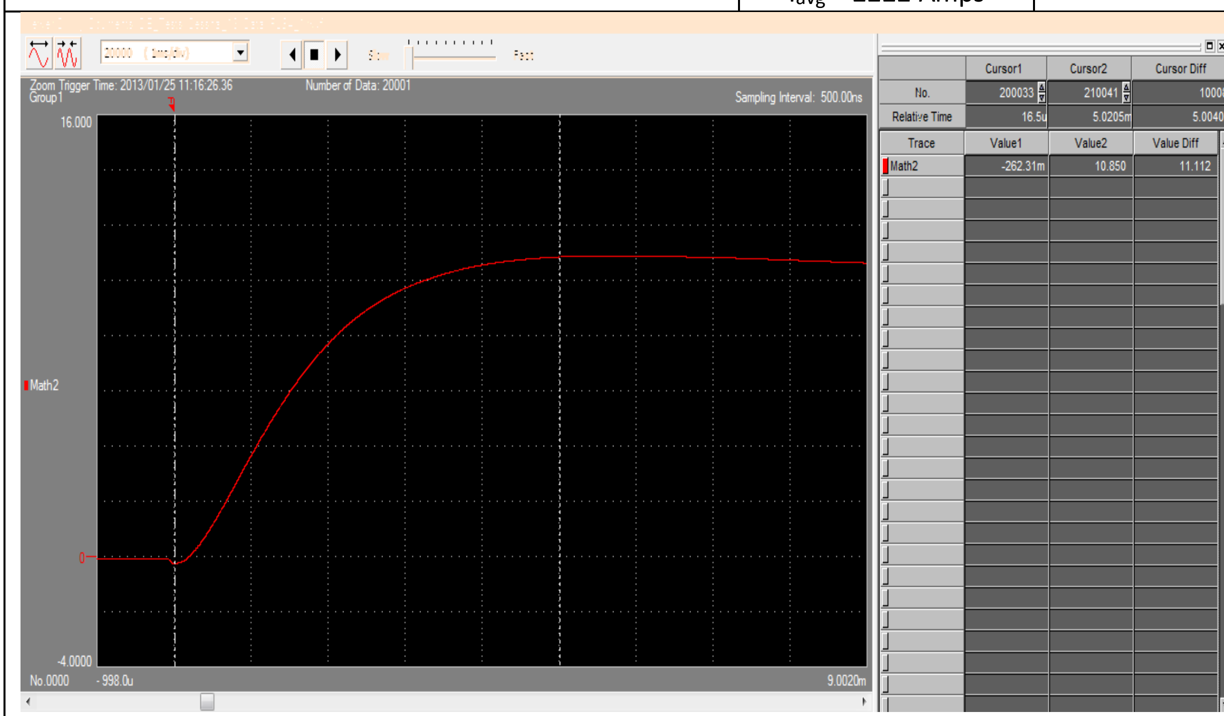


COMPONENT D ACTION INTEGRAL	AI = 268460 A^2-S

Panel: FLS4 – First Strike

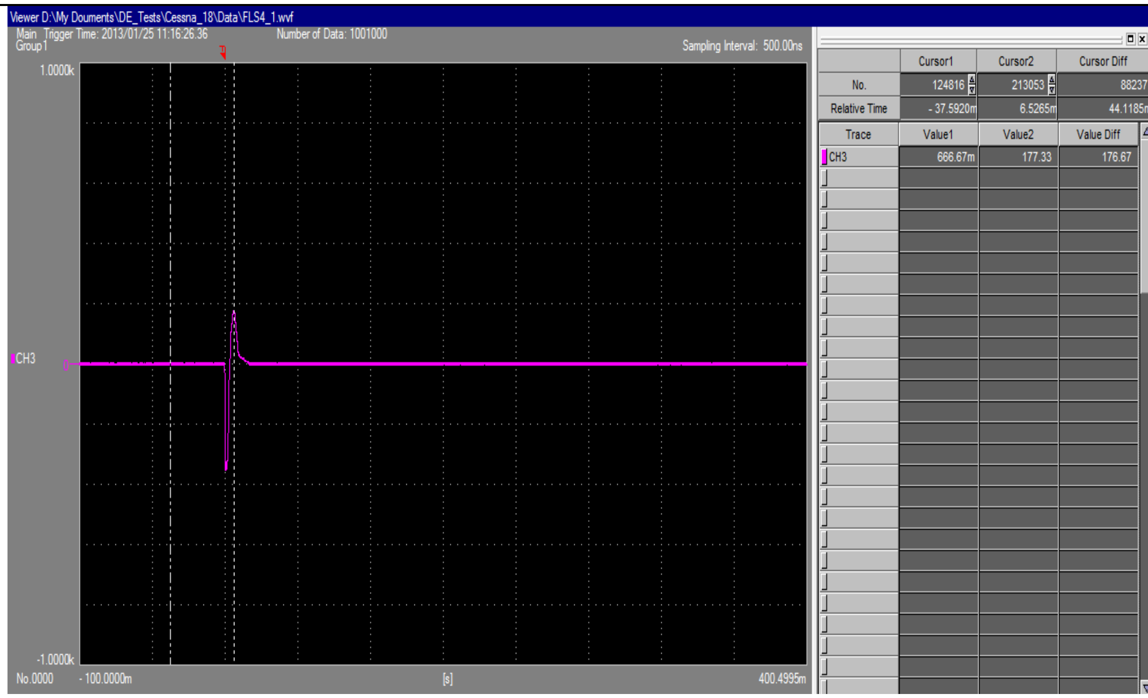


HIGH CURRENT – COMPONENT B	I_P = 5100 Amps I_{avg} = 2222 Amps	1 mS / Div

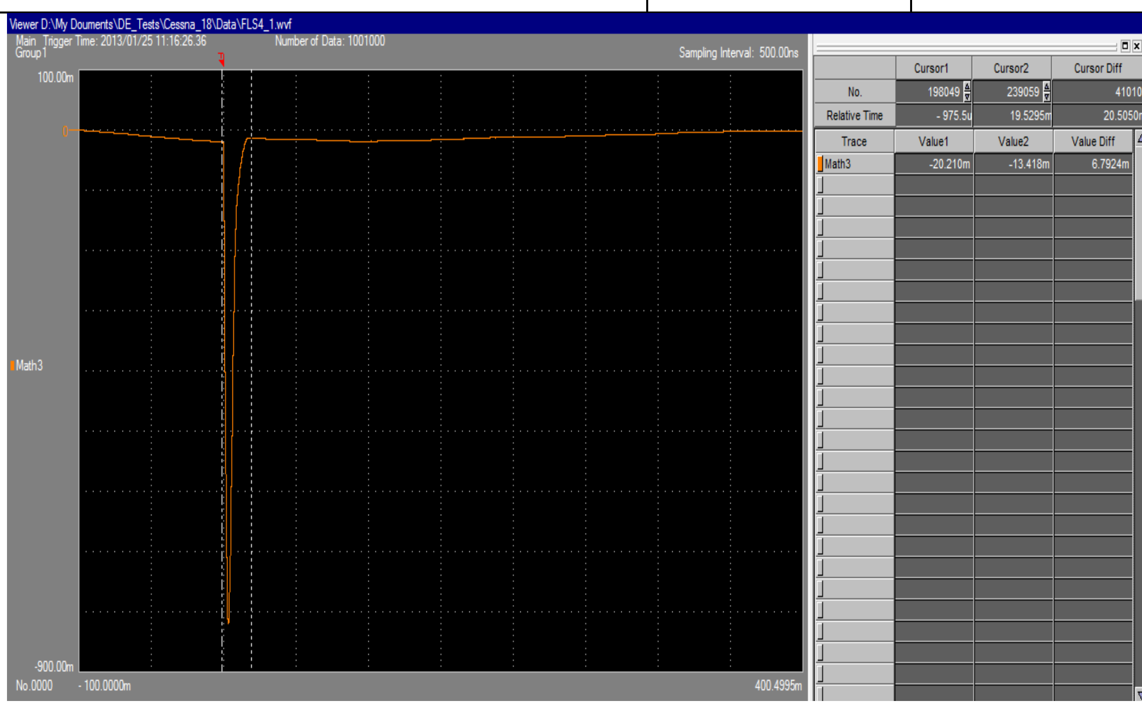


COMPONENT B CHARGE TRANSFER	11.112 Coulombs

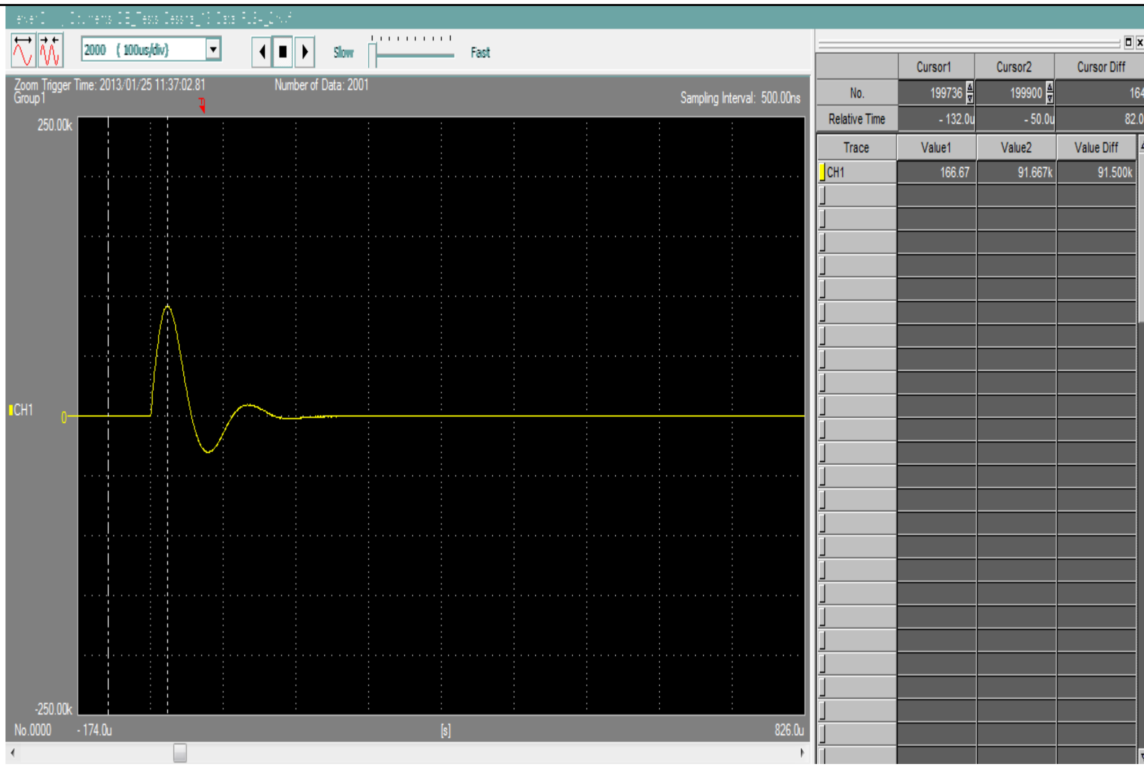
Panel: FLS4 – First Strike



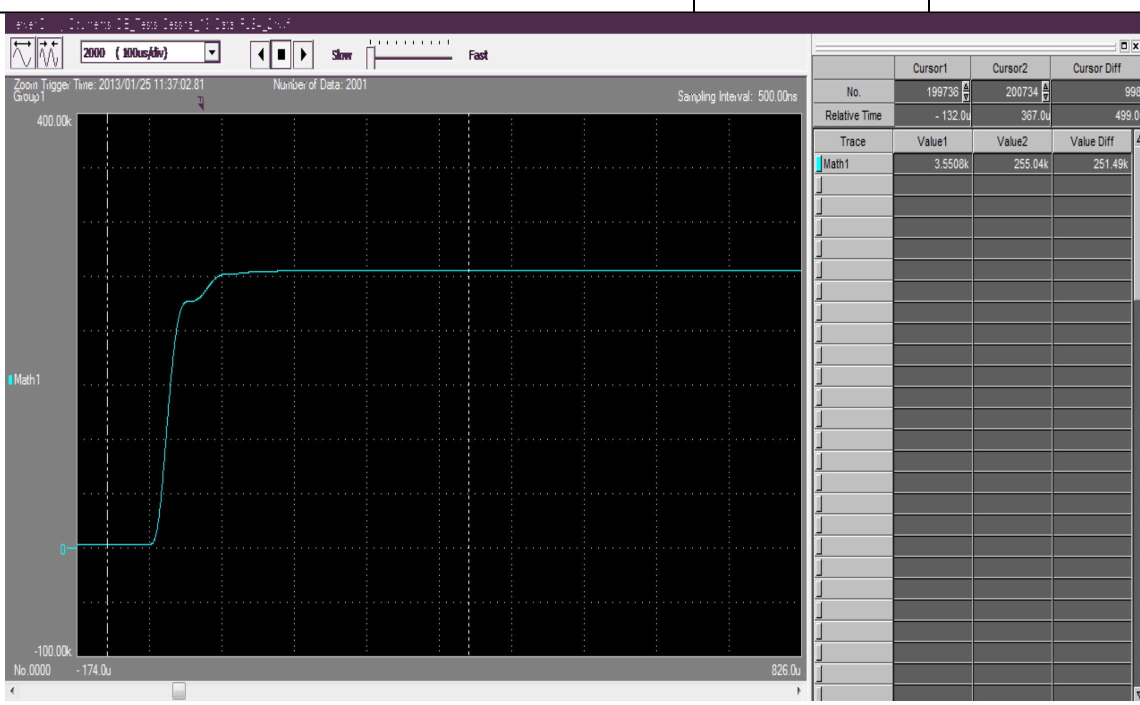
HIGH CURRENT – COMPONENT C*	I_P = 177 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	0.007 Coulombs
Panel: FLS4 – First Strike	

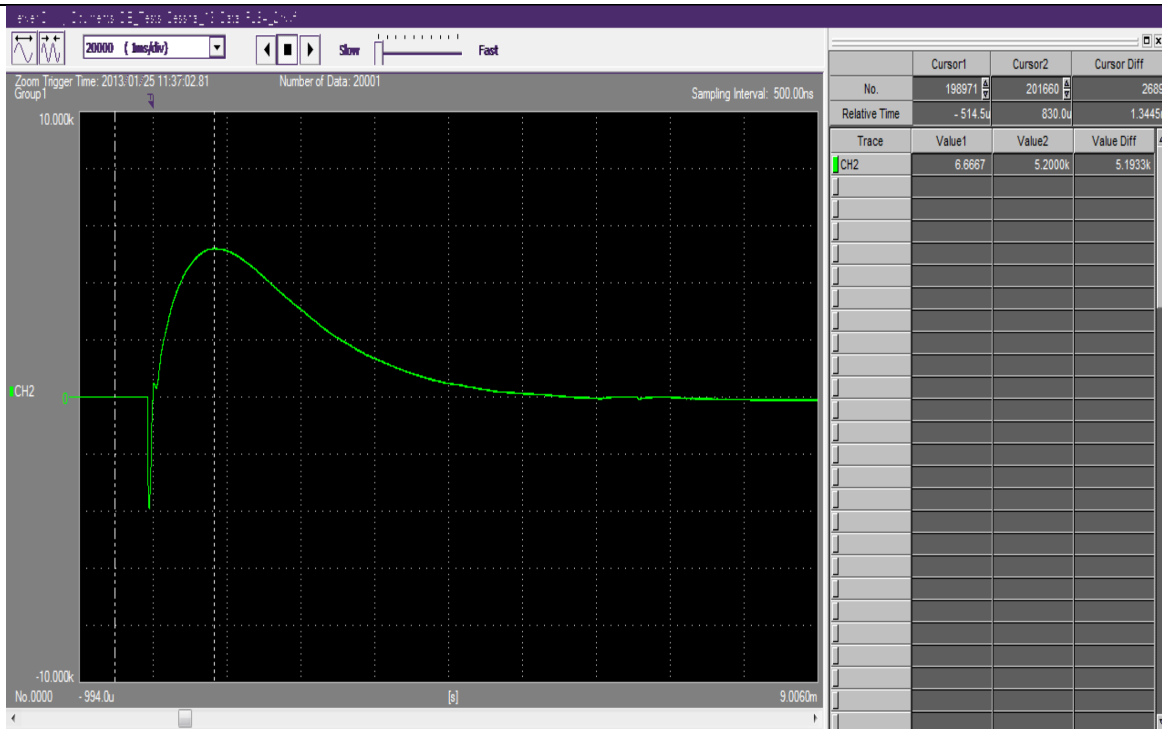


HIGH CURRENT – COMPONENT D	I_P = 91.5 KA	100 uS / Div

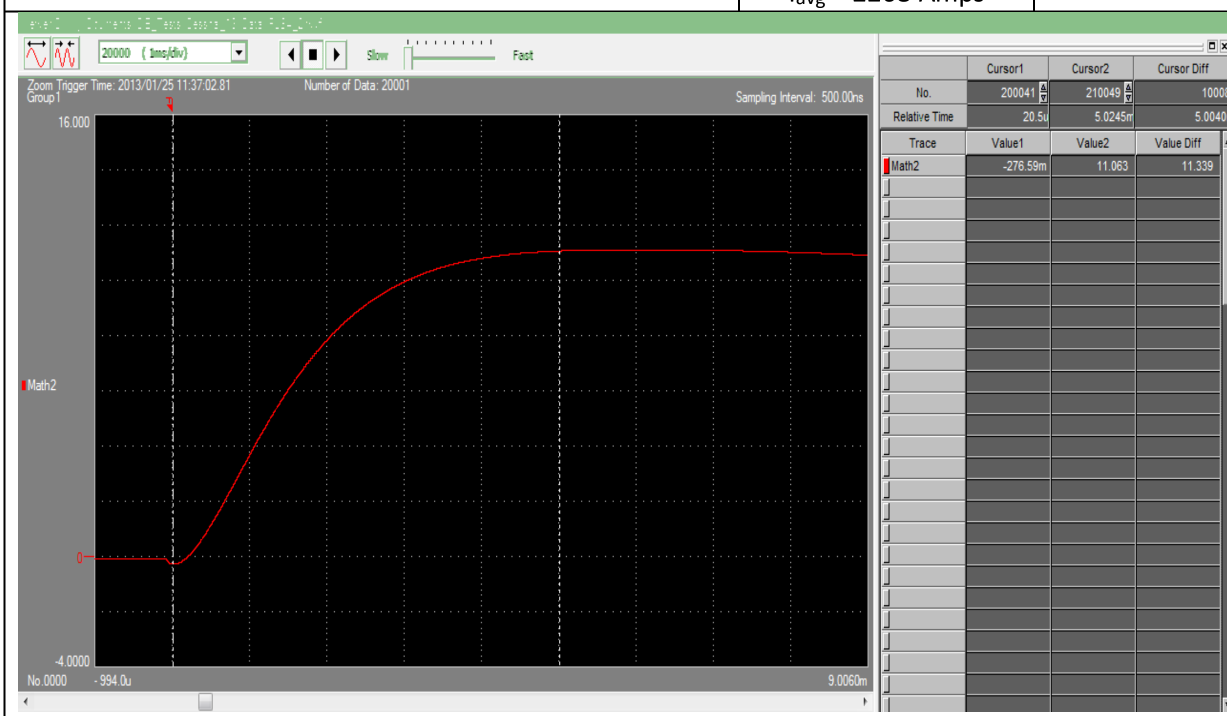


COMPONENT D ACTION INTEGRAL	AI = 251490 A^2-S

Panel: FLS4 – Second Strike

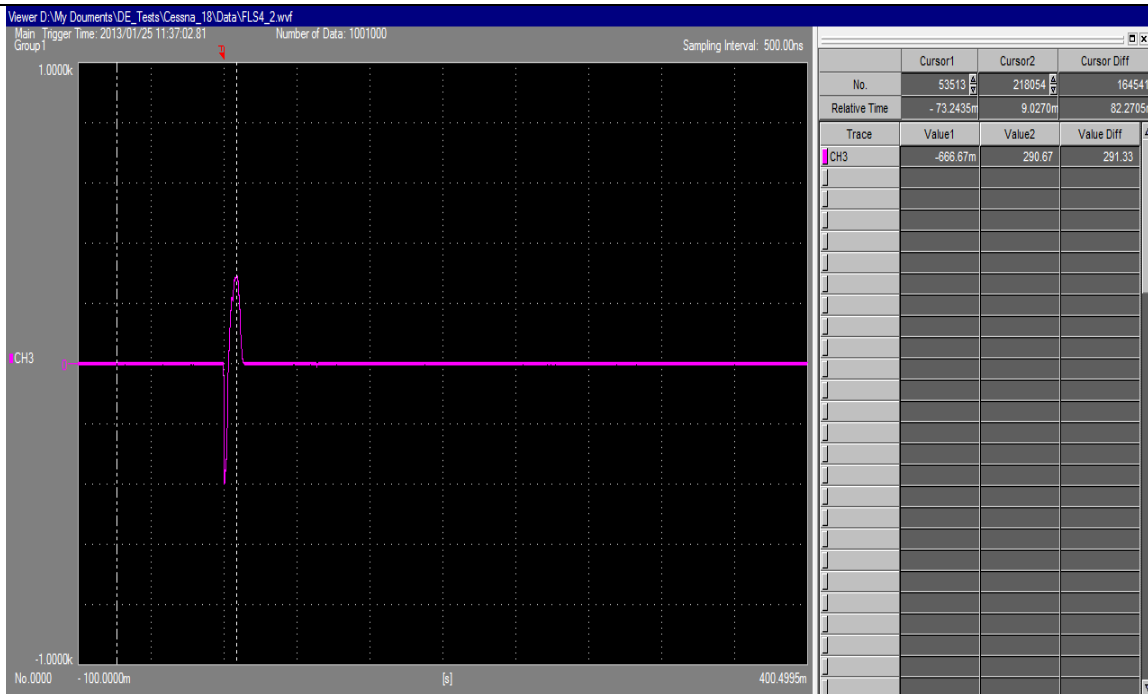


HIGH CURRENT – COMPONENT B	I_P = 5193 Amps I_{avg} = 2268 Amps	1 mS / Div

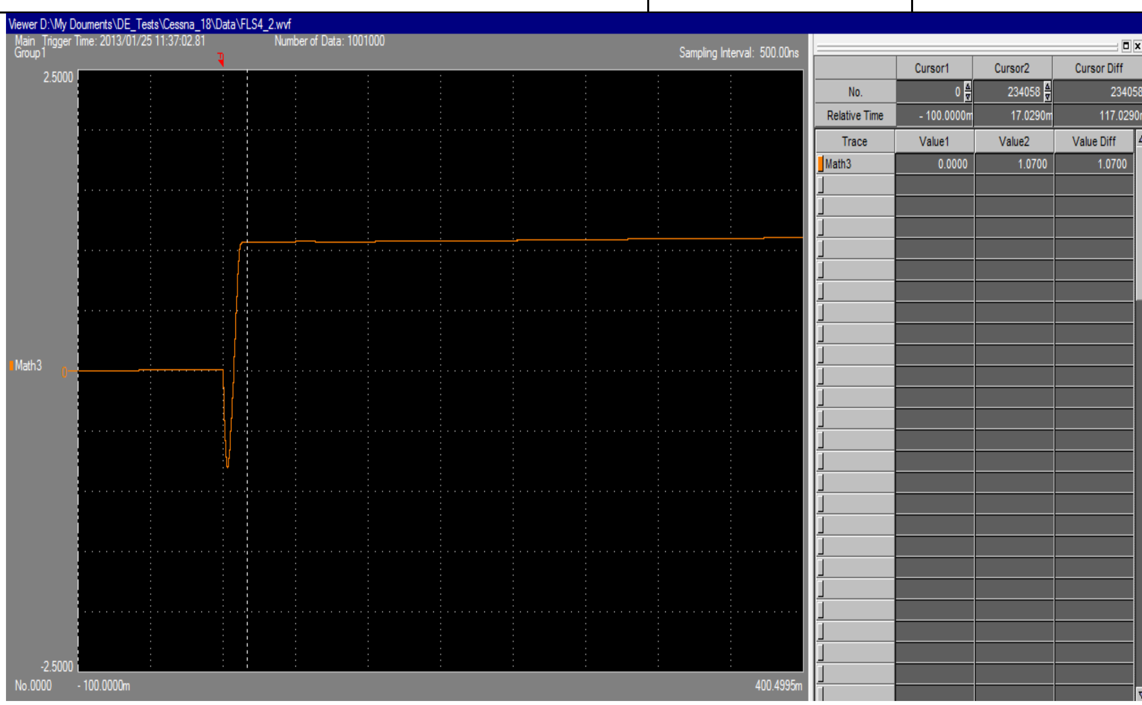


COMPONENT B CHARGE TRANSFER	11.339 Coulombs

Panel: FLS4 – Second Strike

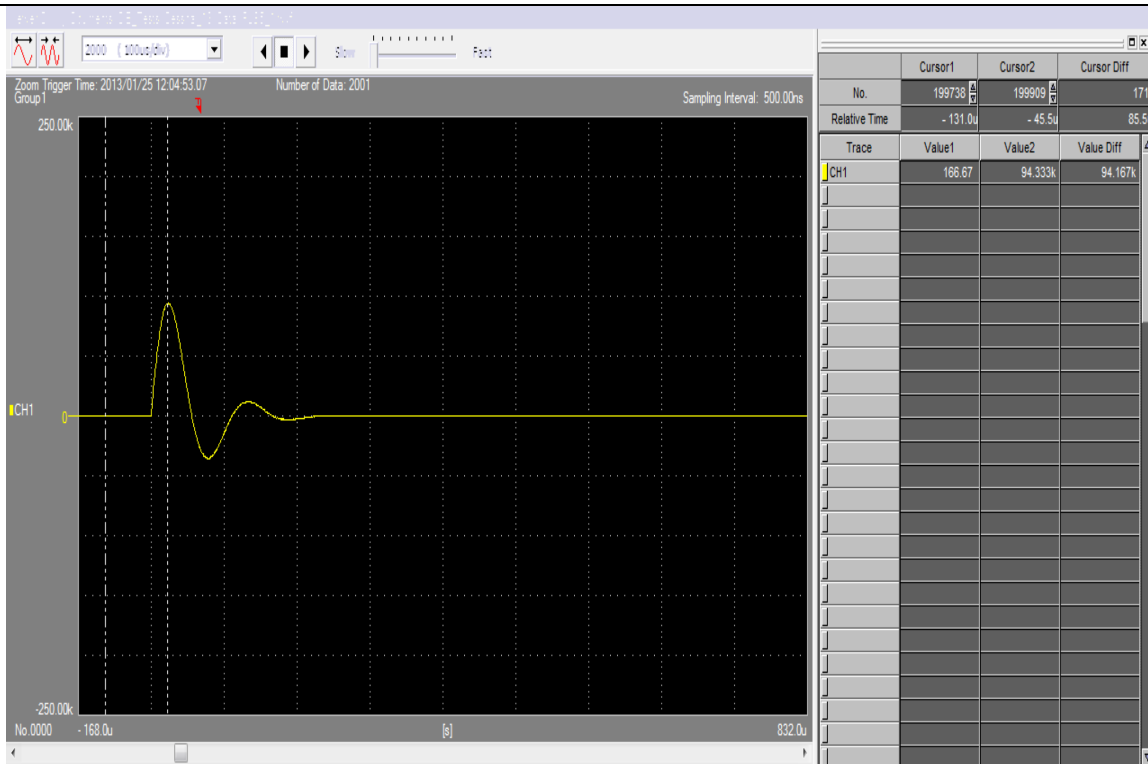


HIGH CURRENT – COMPONENT C*	I_P = 291 Amps	50 mS / Div

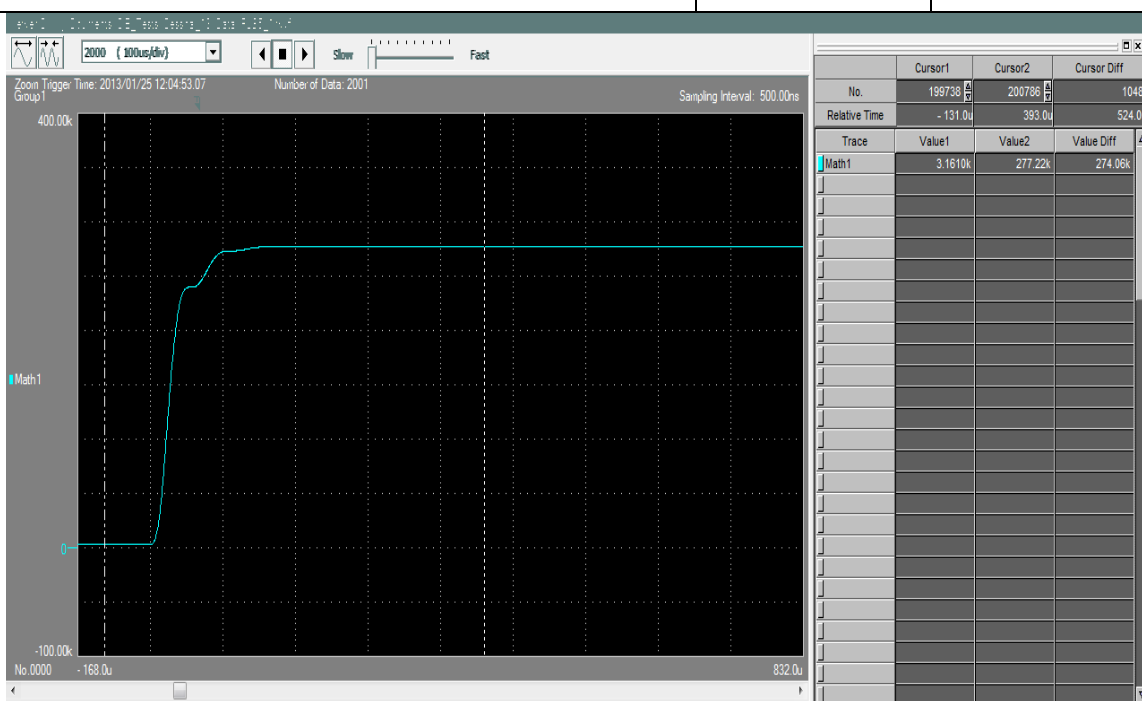


COMPONENT C* CHARGE TRANSFER	1.1 Coulombs

Panel: FLS4 – Second Strike

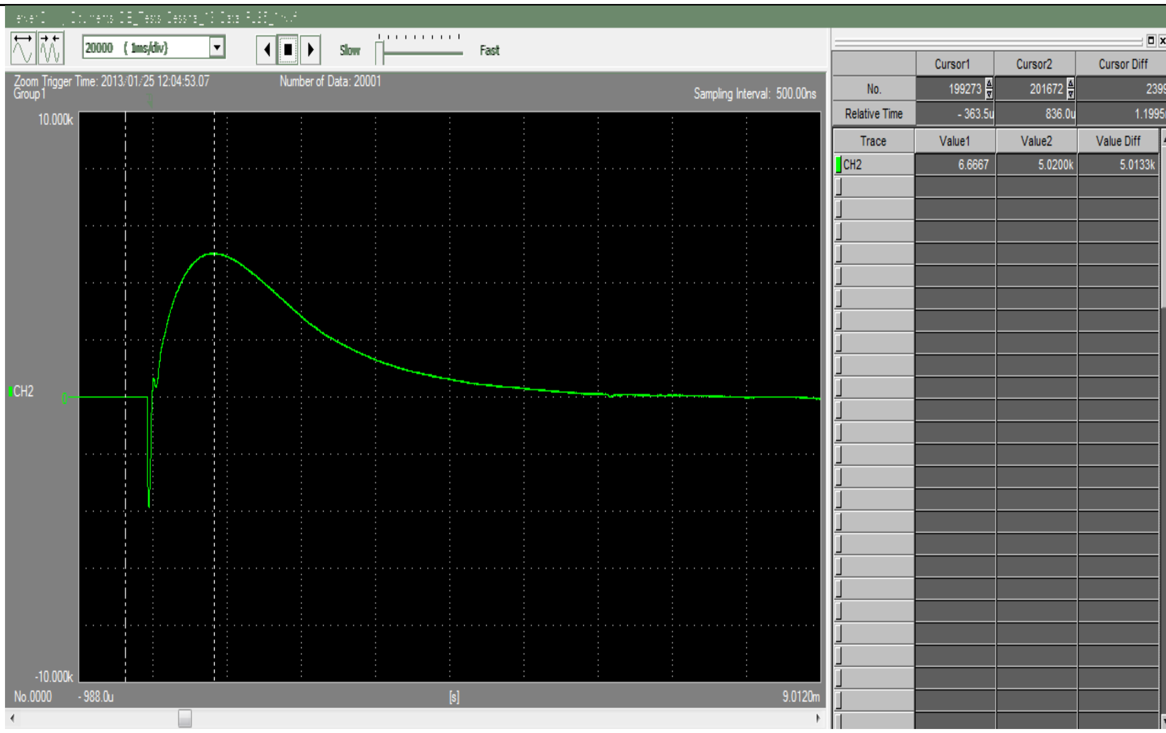


HIGH CURRENT – COMPONENT D	I_P = 94.2 KA	100 uS / Div

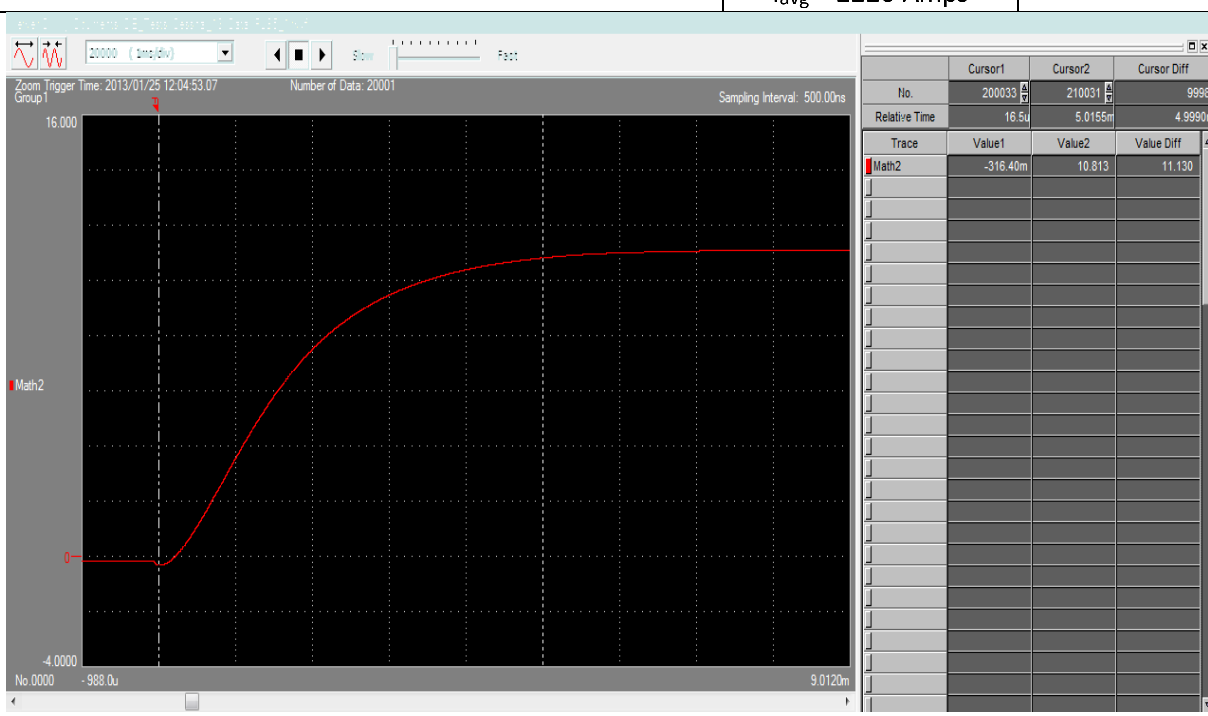


COMPONENT D ACTION INTEGRAL	AI = 274060 A^2-S

Panel: FLS5 – First Strike

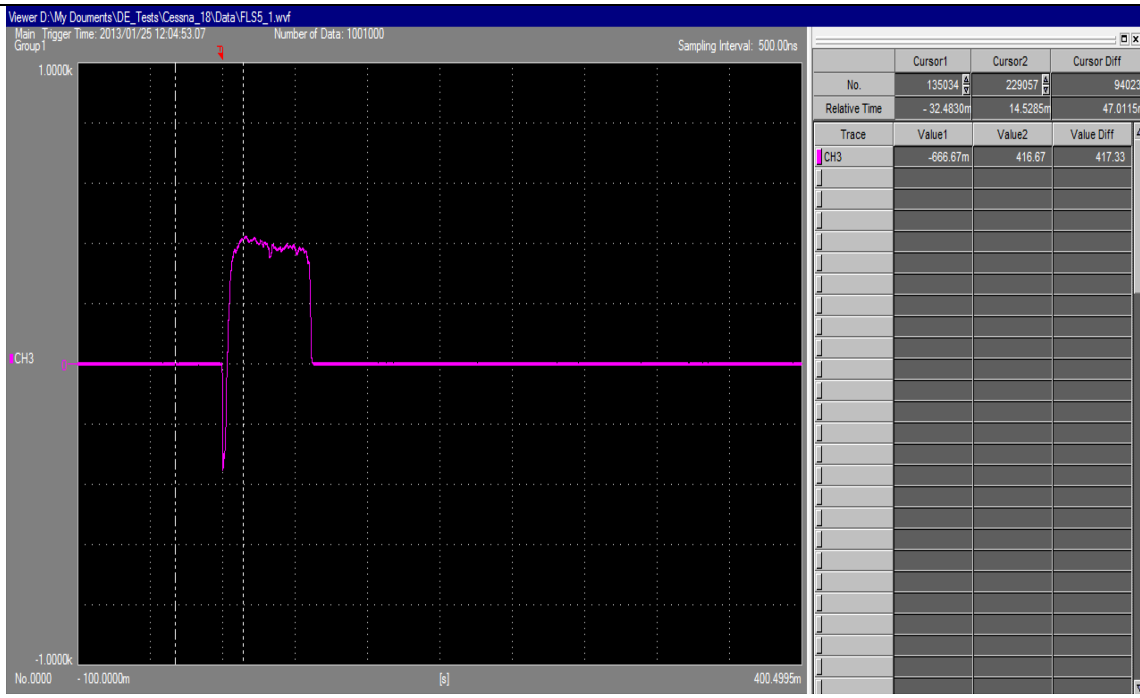


HIGH CURRENT – COMPONENT B	I_P = 5013 Amps I_{avg} = 2226 Amps	1 mS / Div

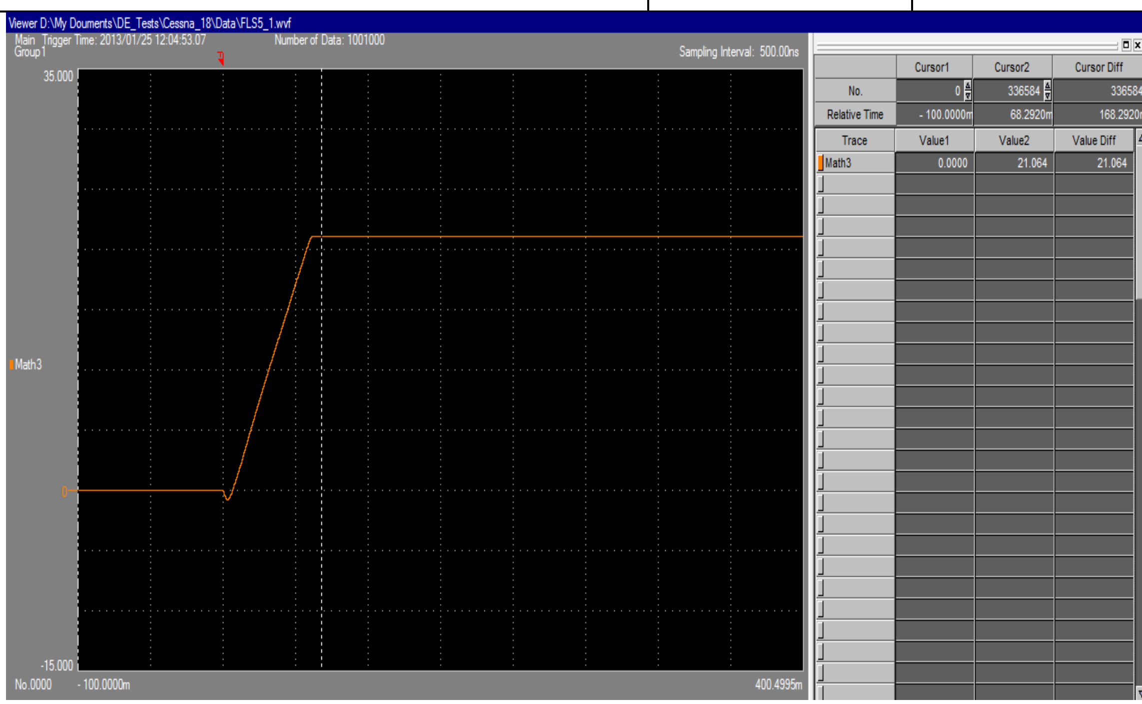


COMPONENT B CHARGE TRANSFER	11.130 Coulombs

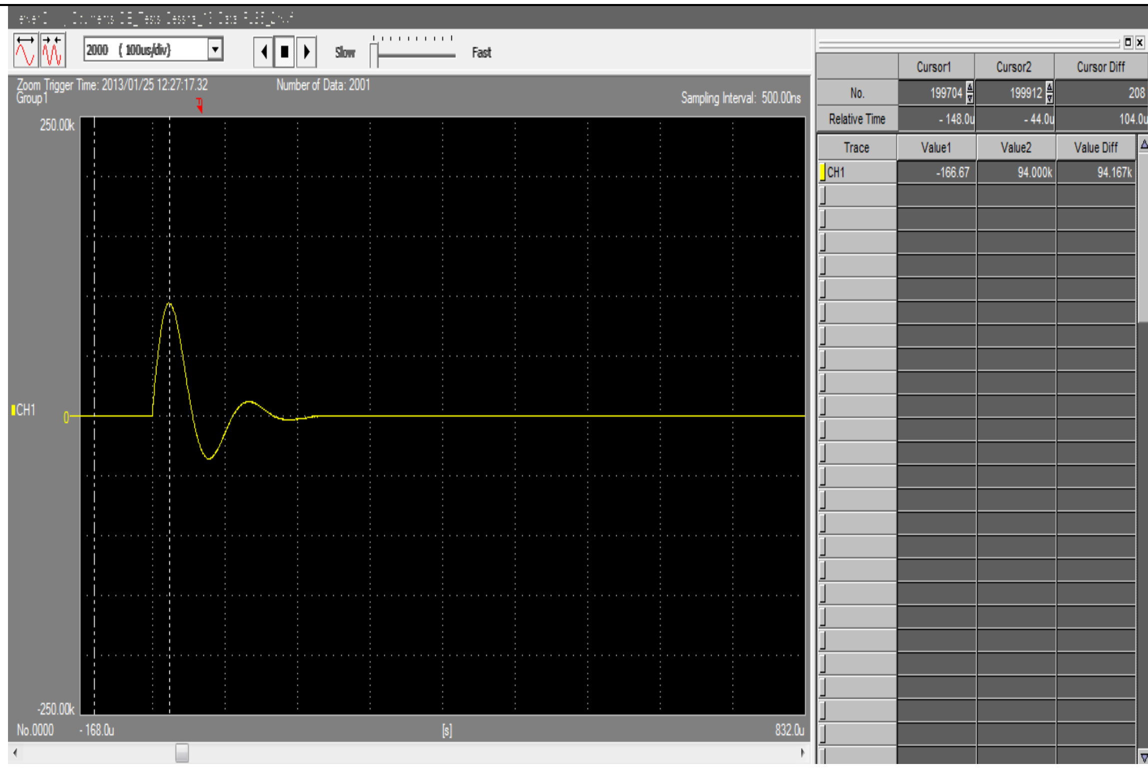
Panel: FLS5 – First Strike



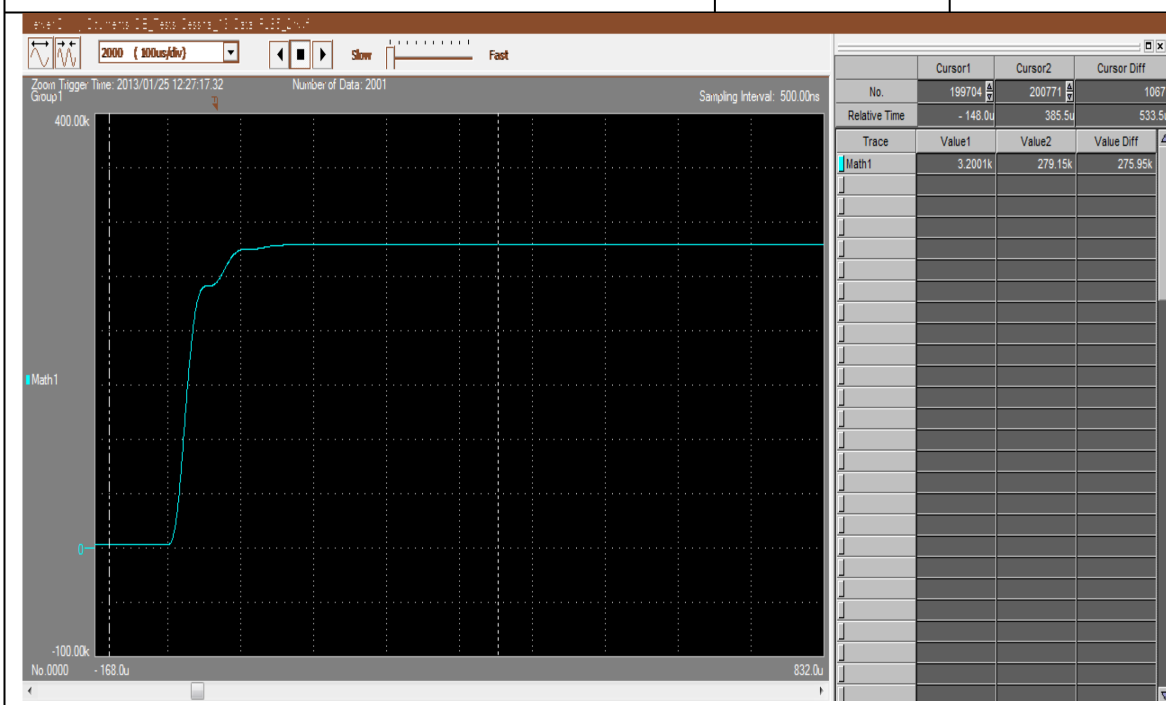
HIGH CURRENT – COMPONENT C*	I_P = 417 Amps	50 mS / Div



COMPONENT C* CHARGE TRANSFER	21.1 Coulombs
Panel: FLS5 – First Strike	

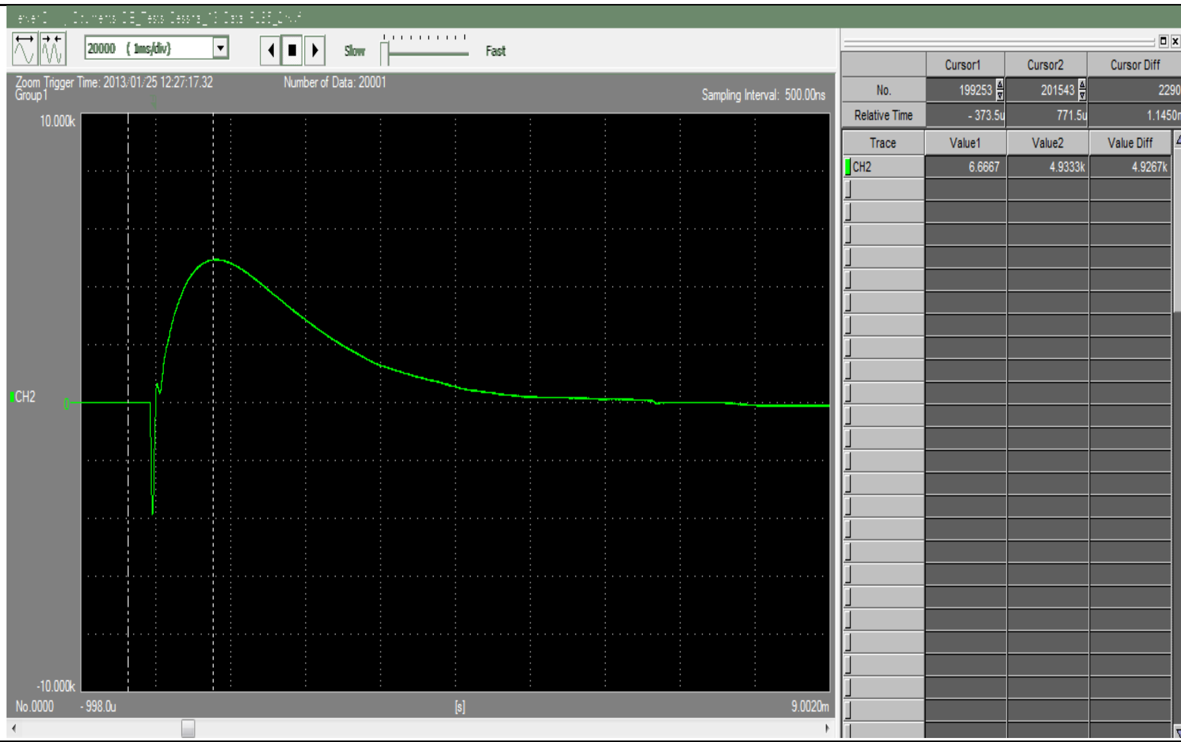


HIGH CURRENT – COMPONENT D	I_P = 94.2 KA	100 uS / Div

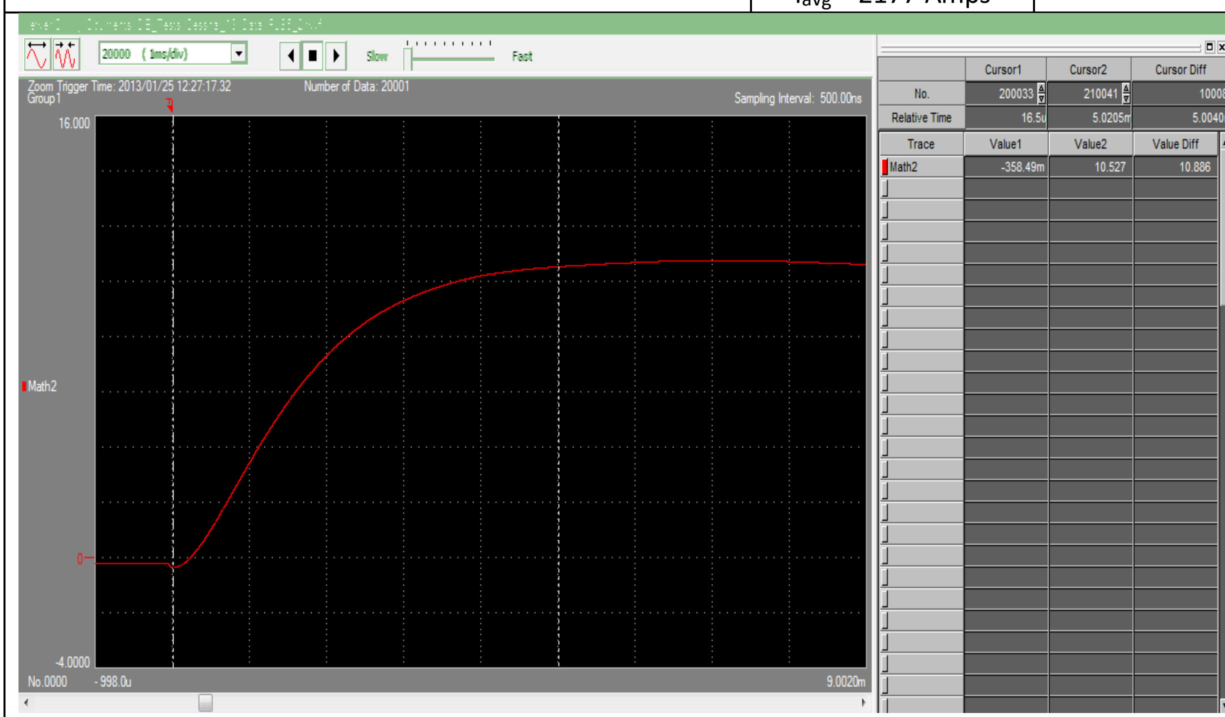


COMPONENT D ACTION INTEGRAL	AI = 275950 A^2-S

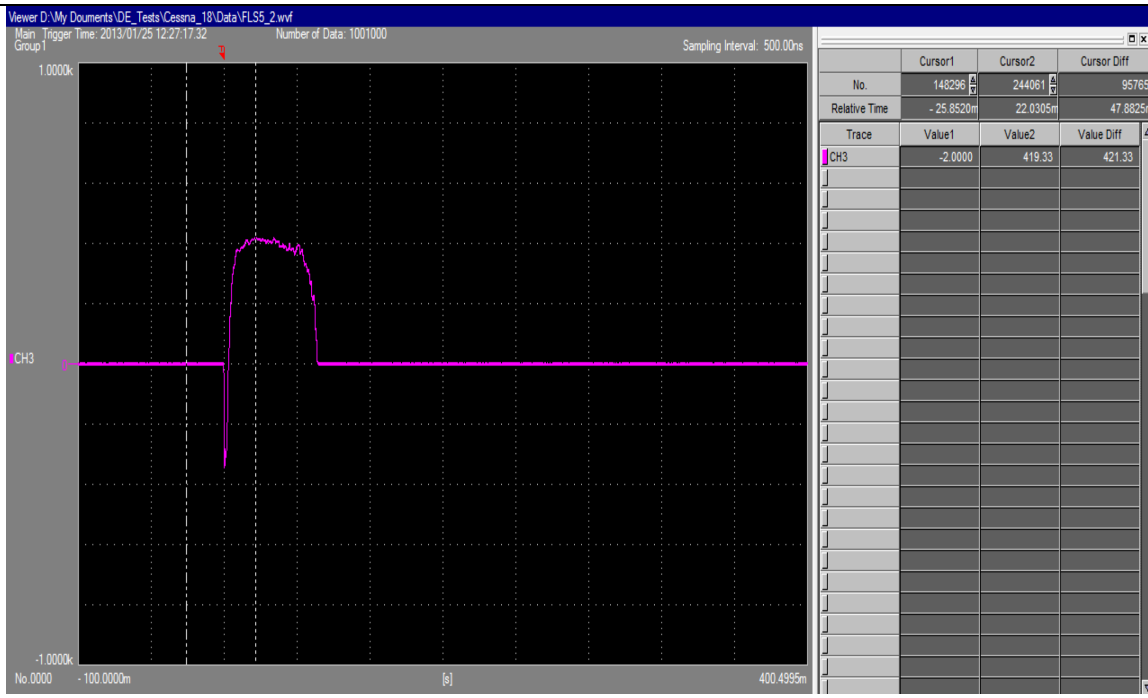
Panel: FLS5 – Second Strike



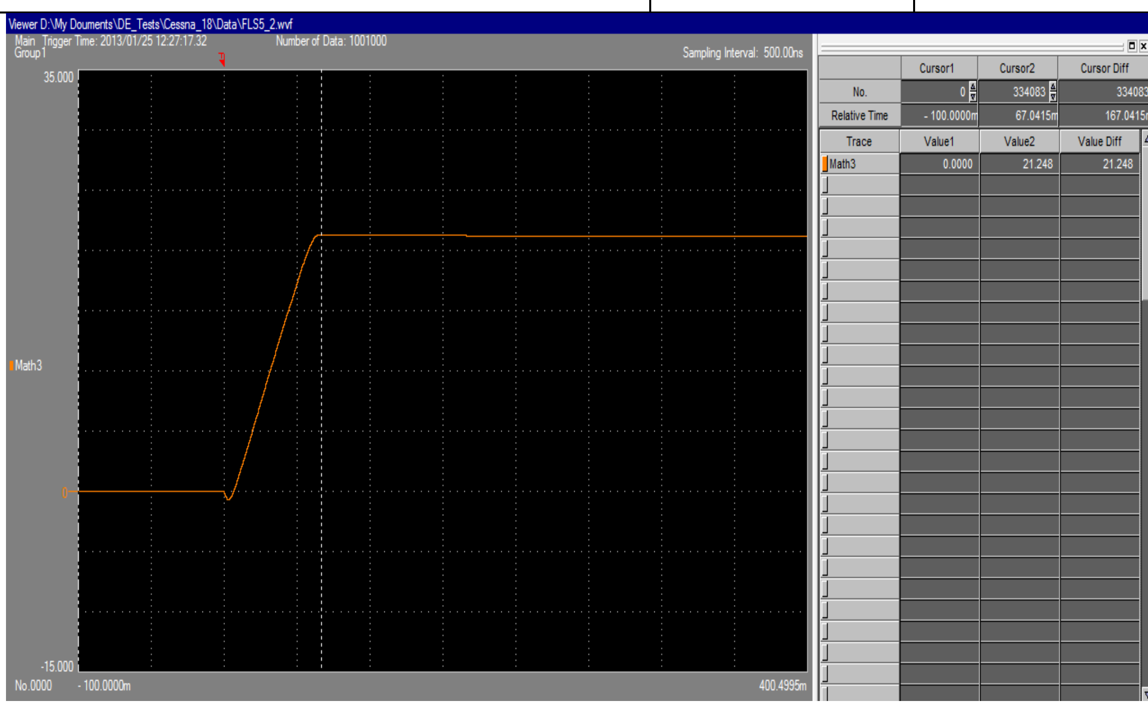
HIGH CURRENT – COMPONENT B	I_P = 4927 Amps I_{avg} = 2177 Amps	1 mS / Div



COMPONENT B CHARGE TRANSFER	10.886 Coulombs
Panel: FLS5 – Second Strike	

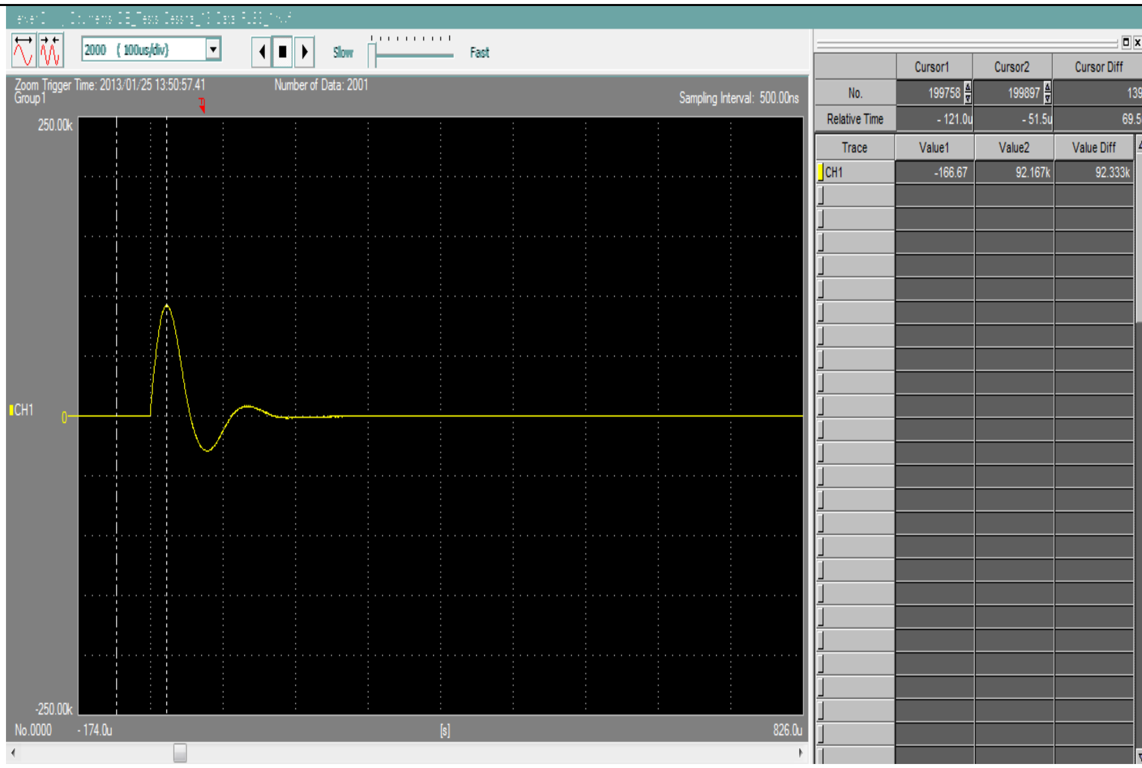


HIGH CURRENT – COMPONENT C*	I_P = 421 Amps	50 mS / Div

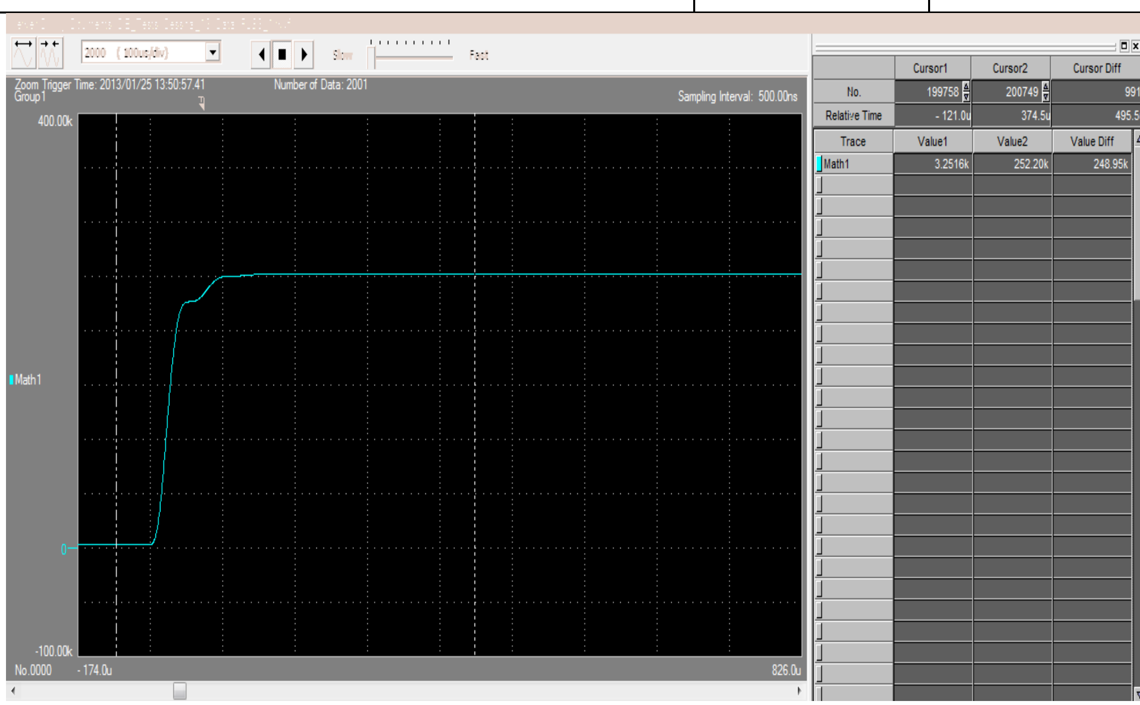


COMPONENT C* CHARGE TRANSFER	21.2 Coulombs

Panel: FLS5 – Second Strike

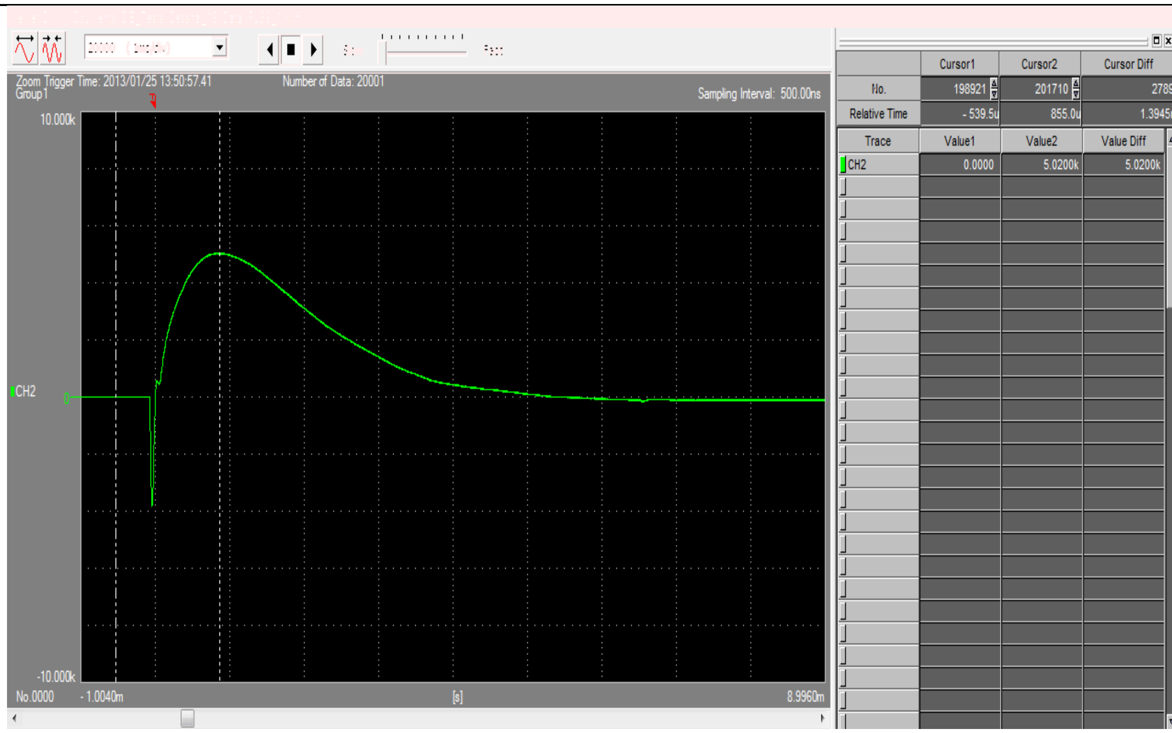


HIGH CURRENT – COMPONENT D	I_P = 92.3 KA	100 uS / Div

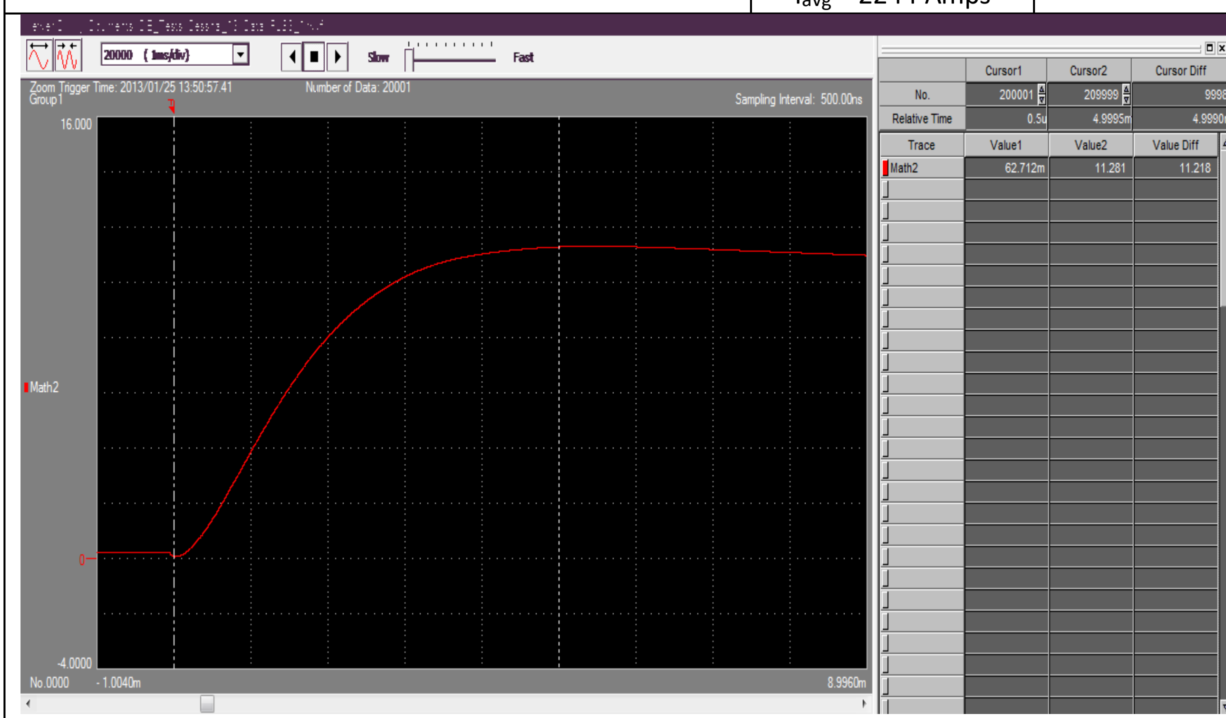


COMPONENT D ACTION INTEGRAL	AI = 248950 A^2-S

Panel: FLS6 – First Strike

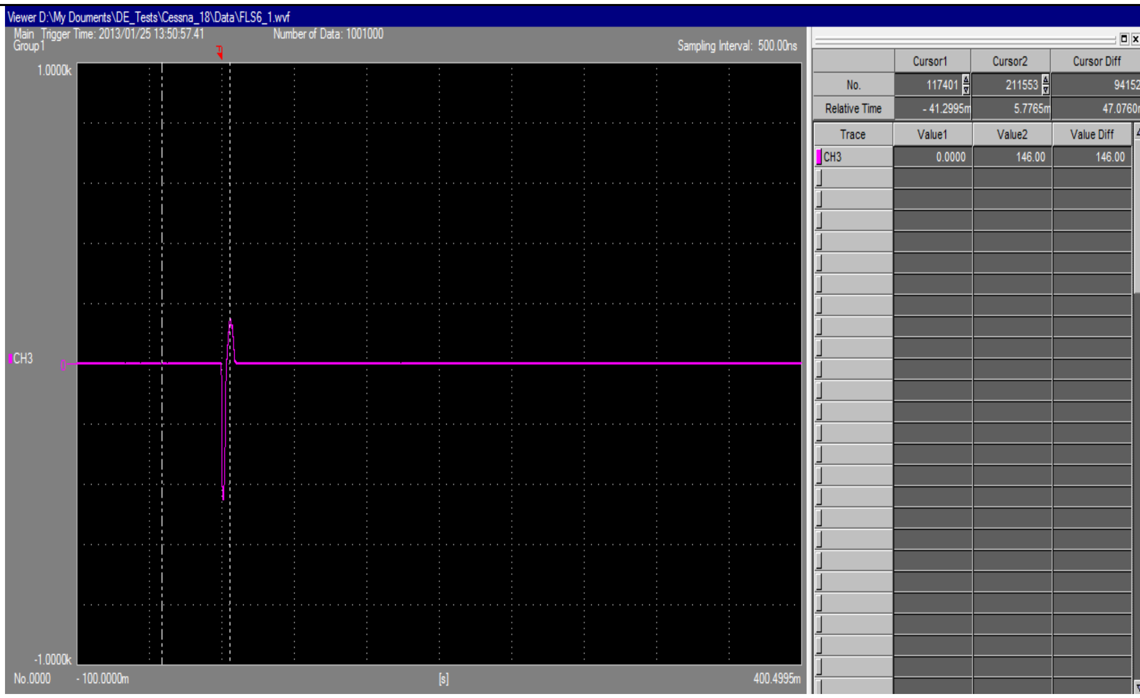


HIGH CURRENT – COMPONENT B	I_P = 5020 Amps I_{avg} = 2244 Amps	1 mS / Div

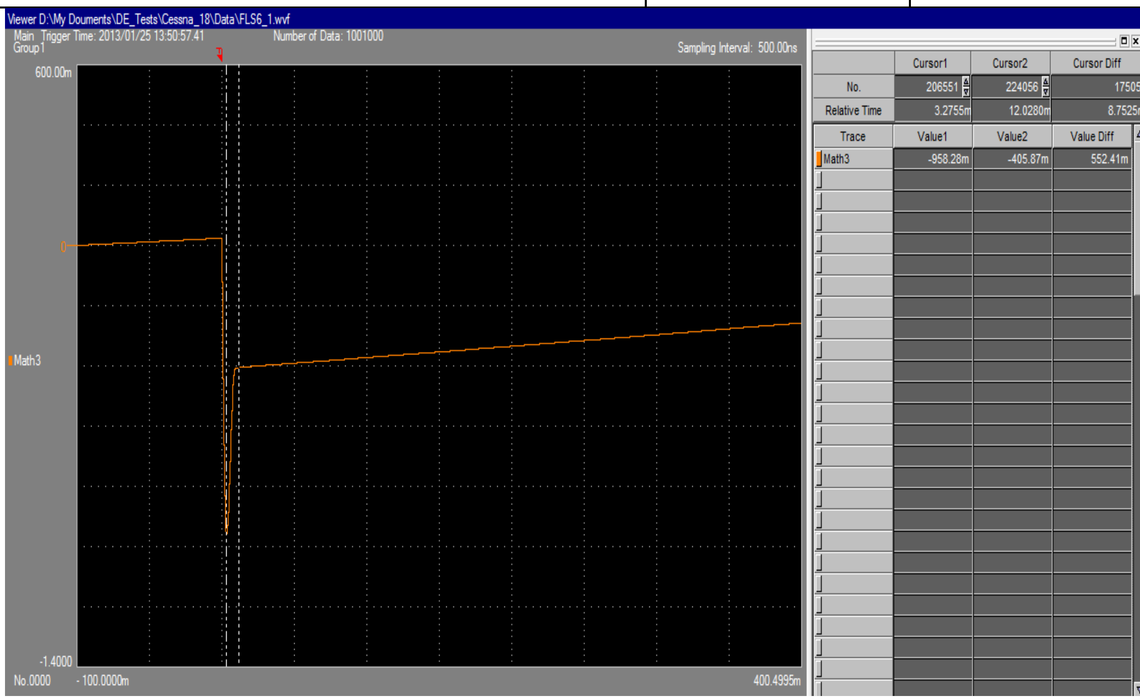


COMPONENT B CHARGE TRANSFER	11.218 Coulombs

Panel: FLS6 – First Strike

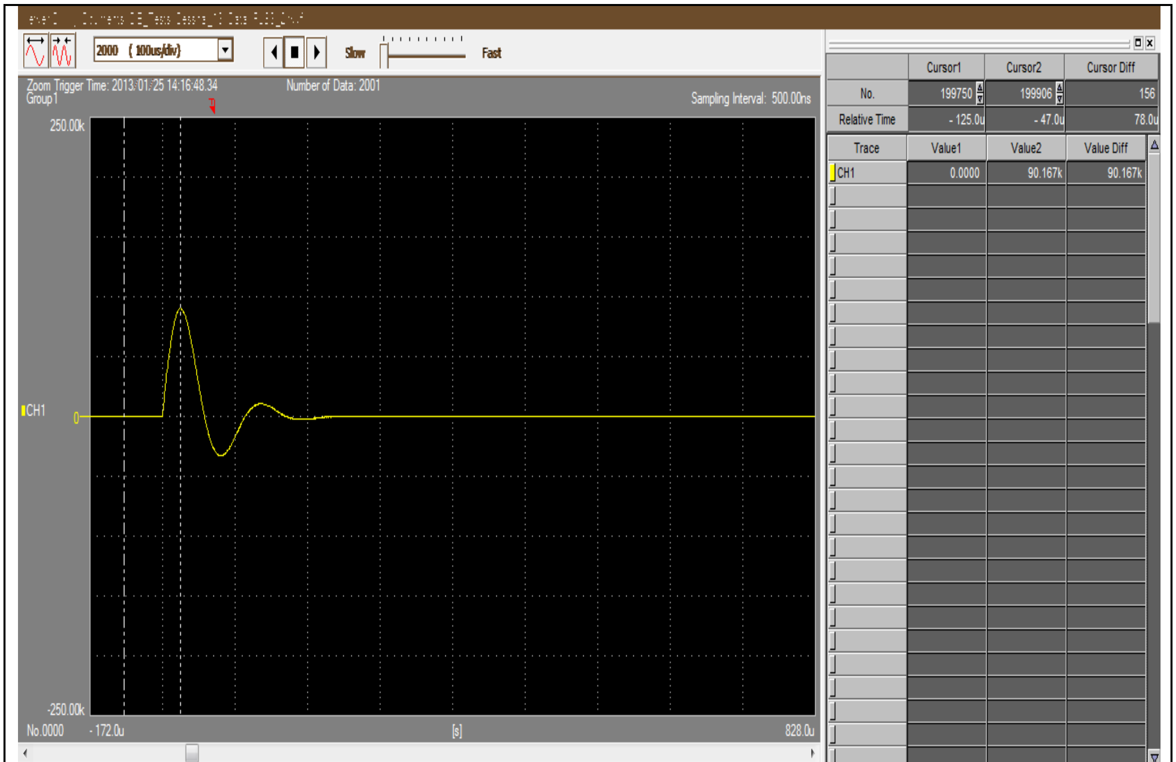


HIGH CURRENT – COMPONENT C*	I_P = 146 Amps	50 mS / Div

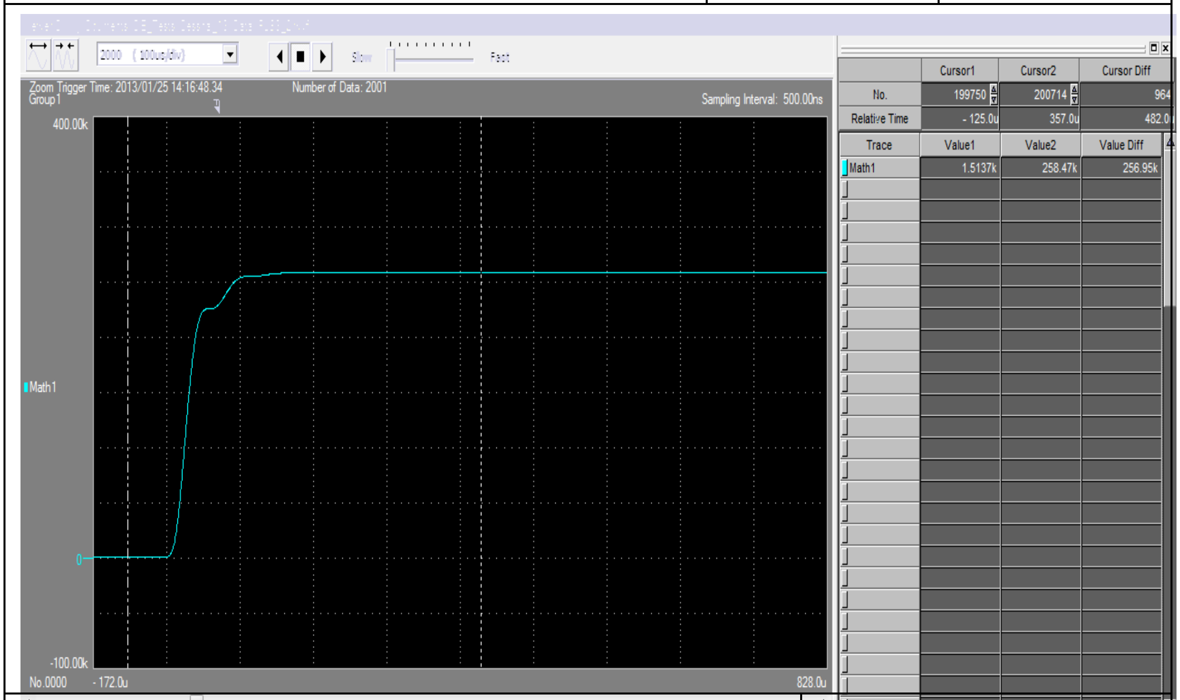


COMPONENT C* CHARGE TRANSFER	0.55 Coulombs

Panel: FLS6 – First Strike

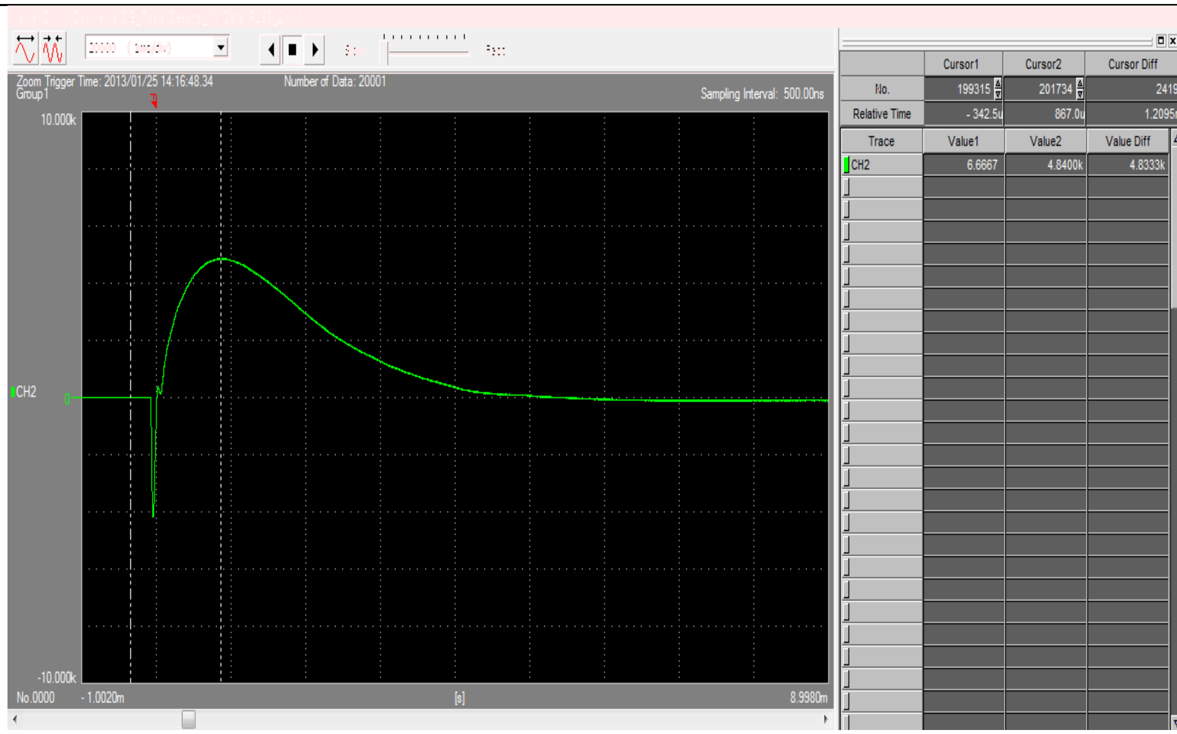


HIGH CURRENT – COMPONENT D	I_P = 90.2 KA	100 uS / Div

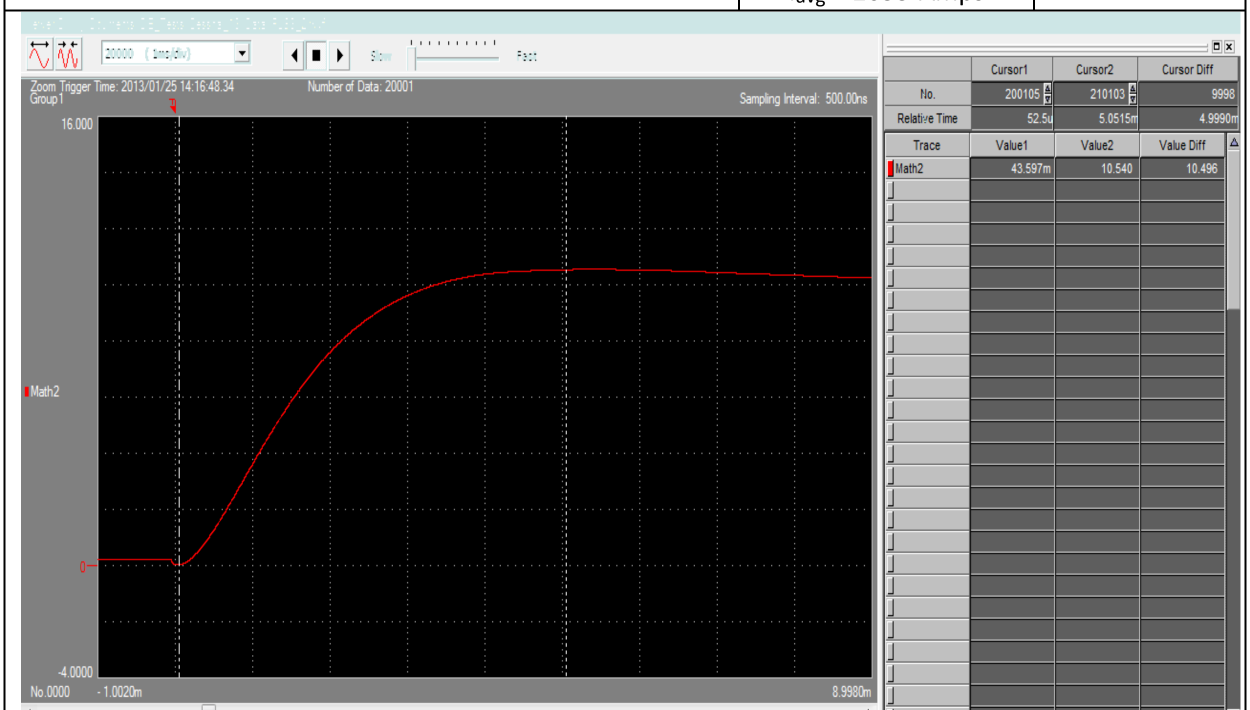


COMPONENT D ACTION INTEGRAL	AI = 256950 A^2-S

Panel: FLS6 – Second Strike

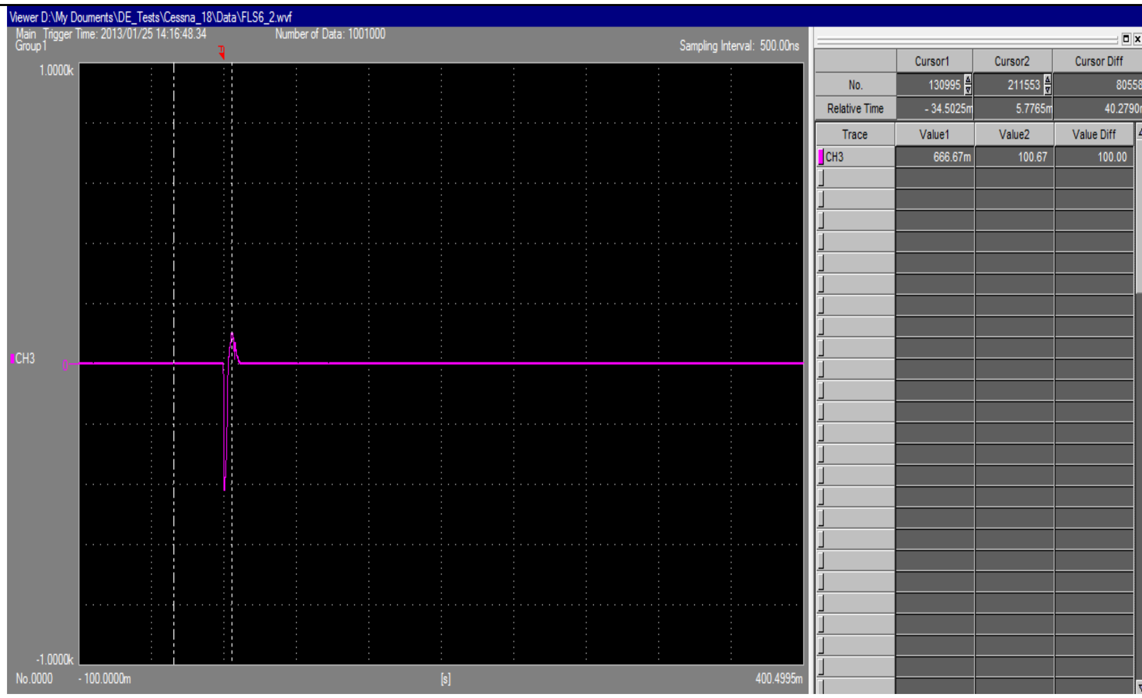


HIGH CURRENT – COMPONENT B	I_P = 4833 Amps I_{avg} = 2099 Amps	1 mS / Div

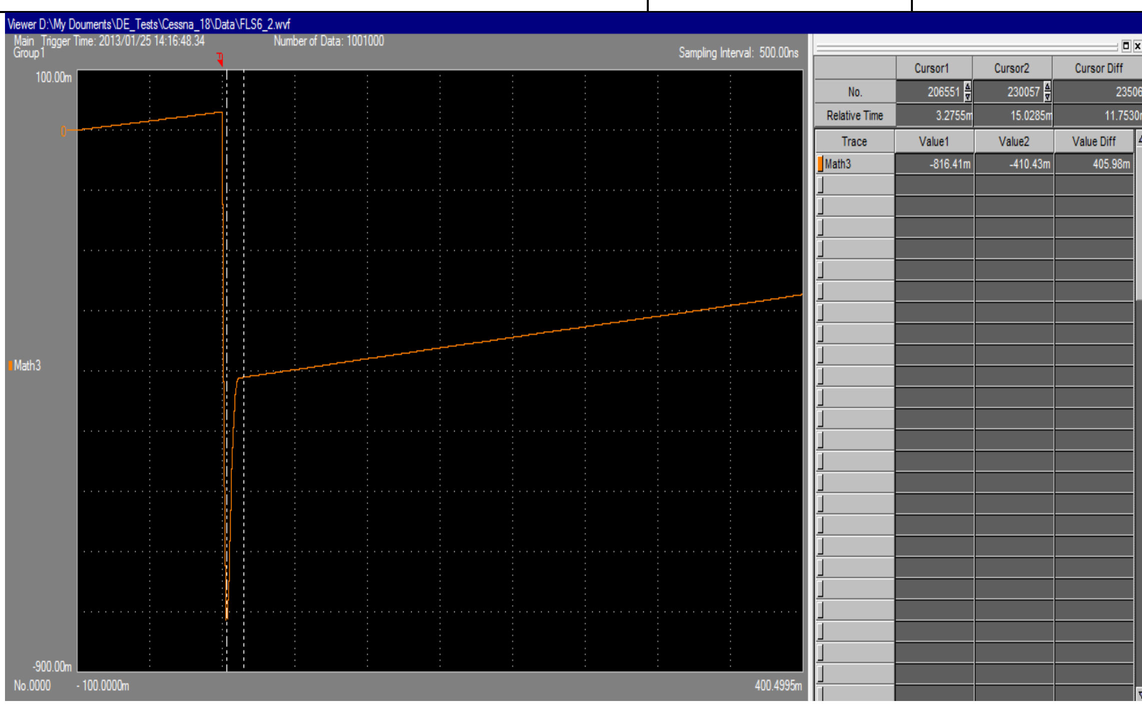


COMPONENT B CHARGE TRANSFER	10.496 Coulombs

Panel: FLS6 – Second Strike

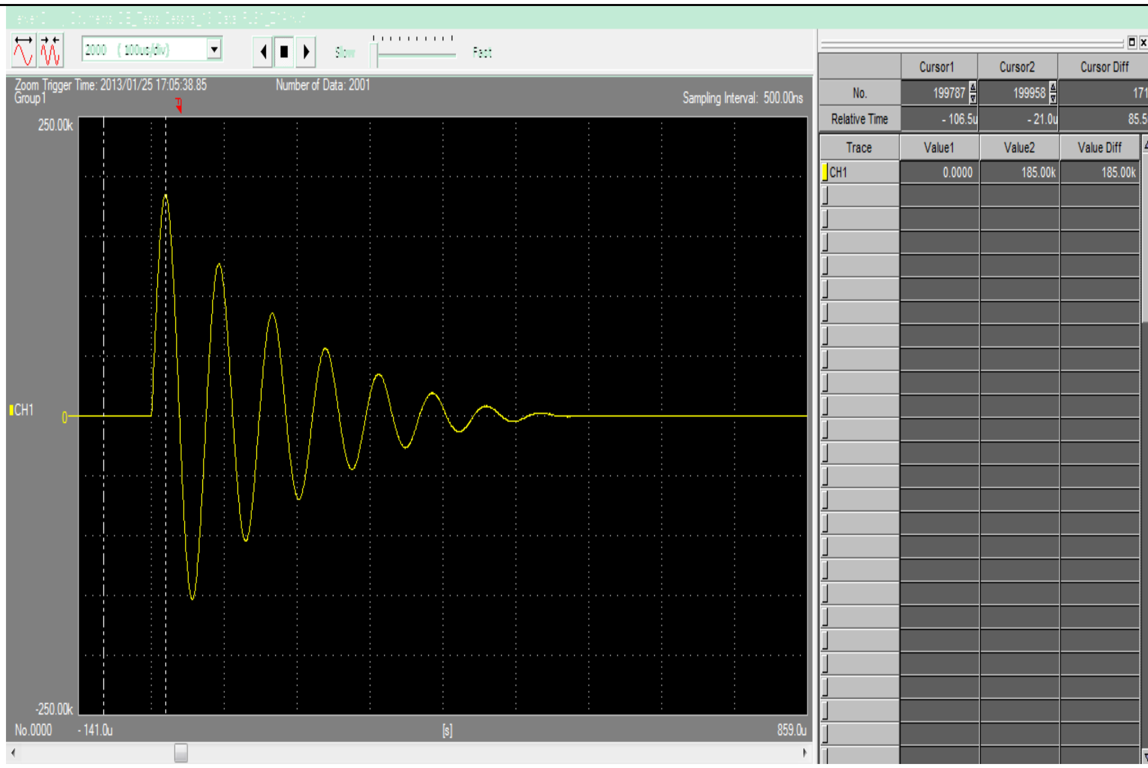


HIGH CURRENT – COMPONENT C*	I_P = 100 Amps	50 mS / Div

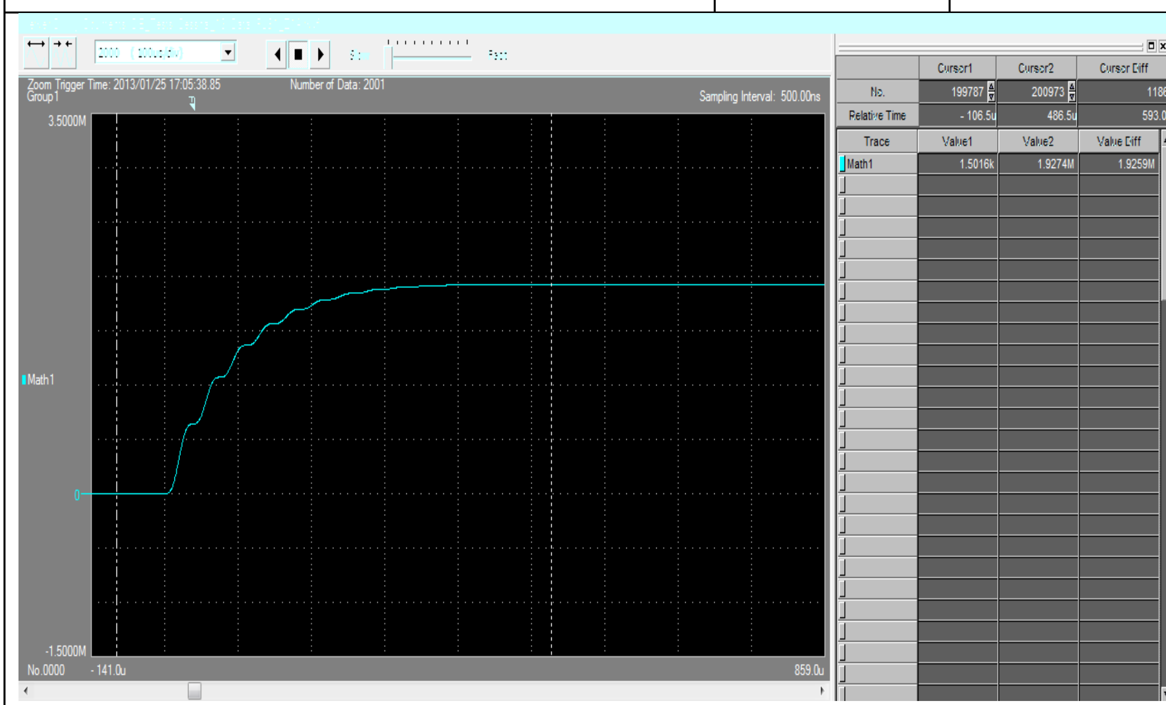


COMPONENT C* CHARGE TRANSFER	0.41 Coulombs

Panel: FLS6 – Second Strike

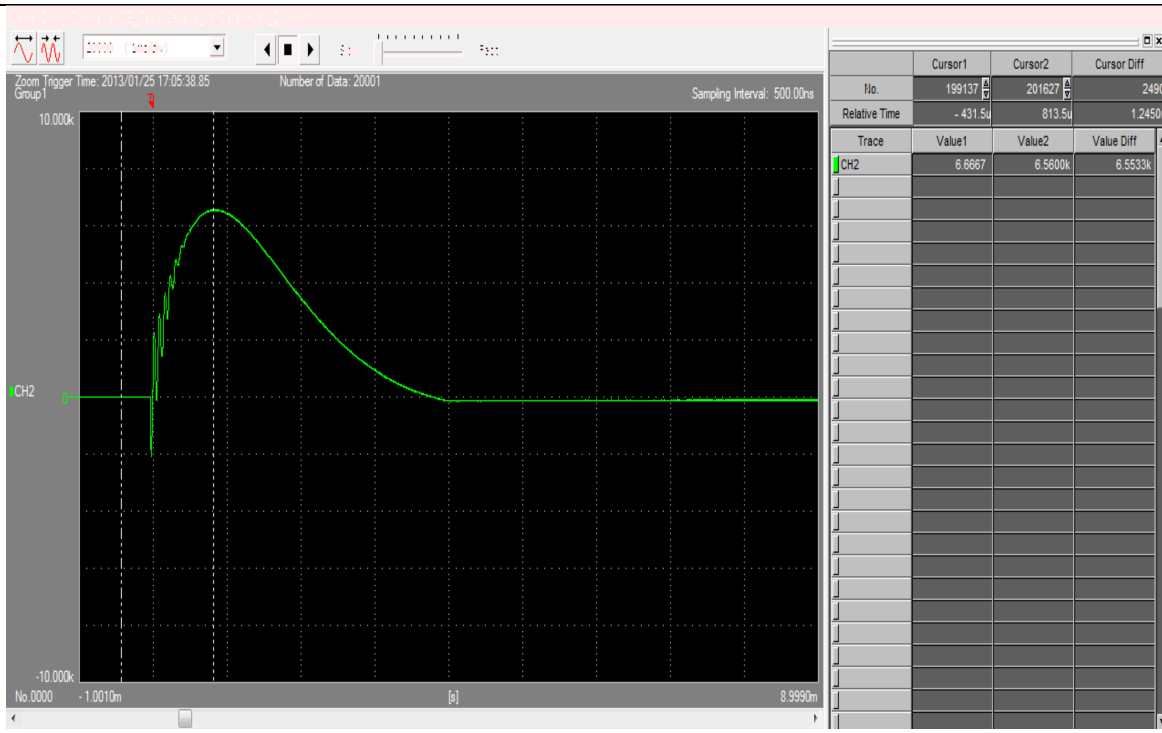


HIGH CURRENT – COMPONENT A	I_P = 185.0 KA	100 uS / Div

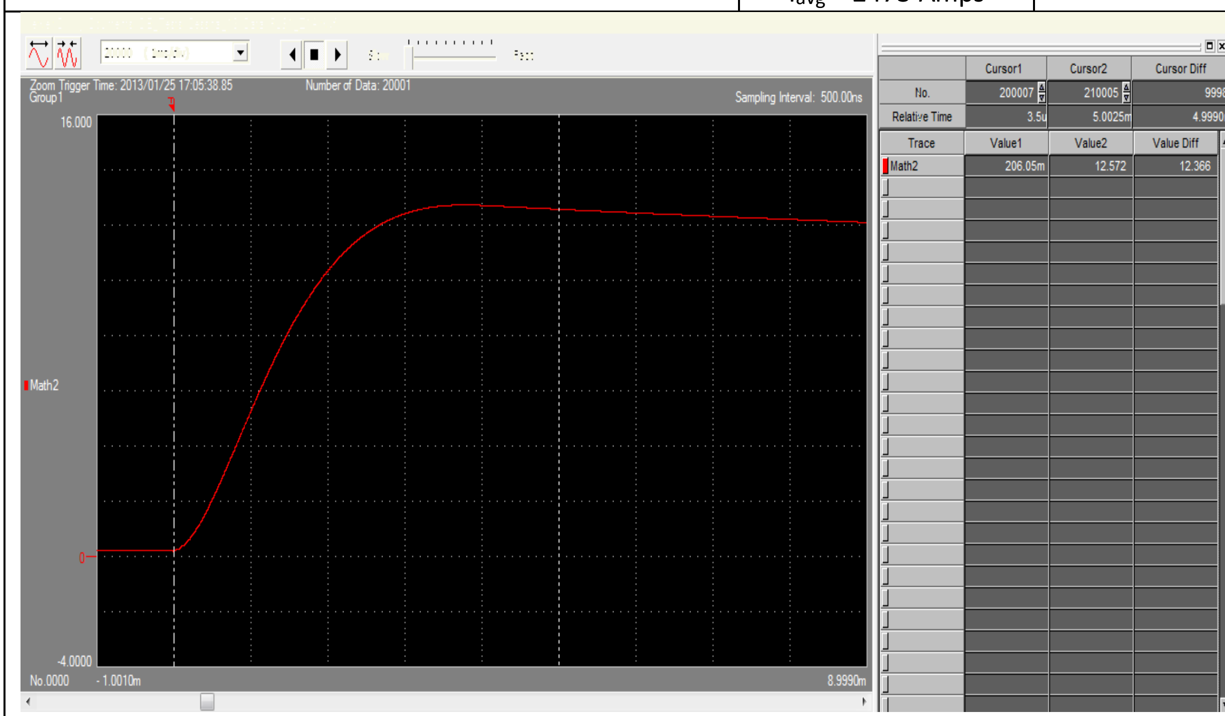


COMPONENT A ACTION INTEGRAL	AI = 1.9259E6 A^2-S

Panel: FLS1 – Third Strike (Zone 1A)

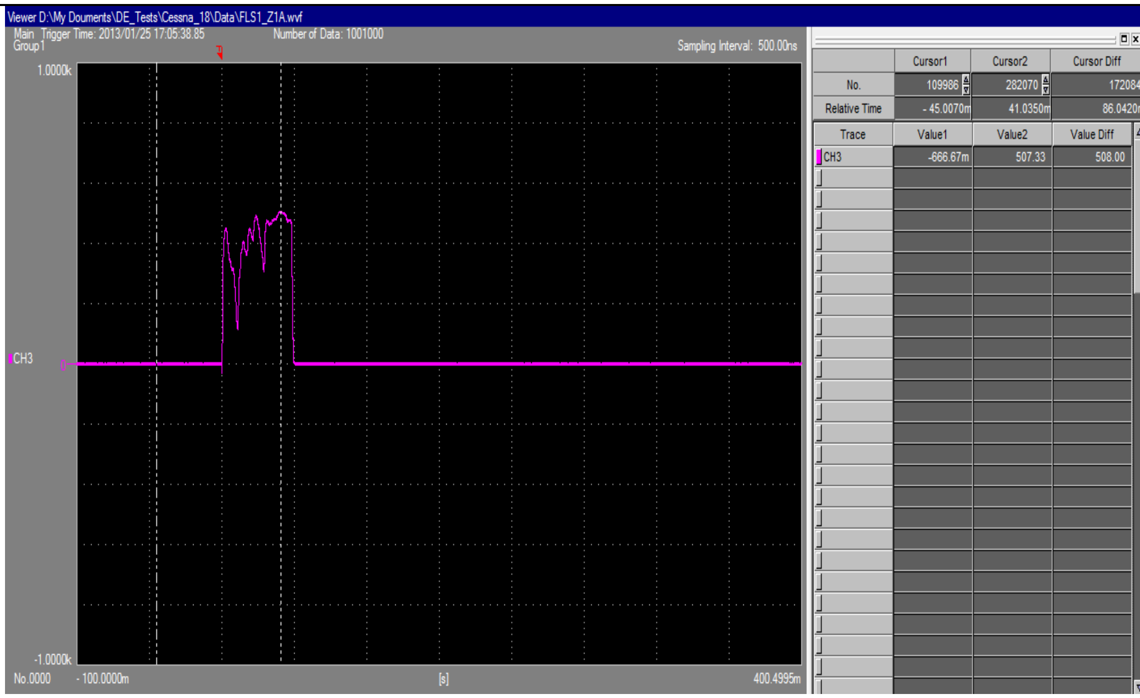


HIGH CURRENT – COMPONENT B	I_P = 6553 Amps I_{avg} = 2473 Amps	1 mS / Div

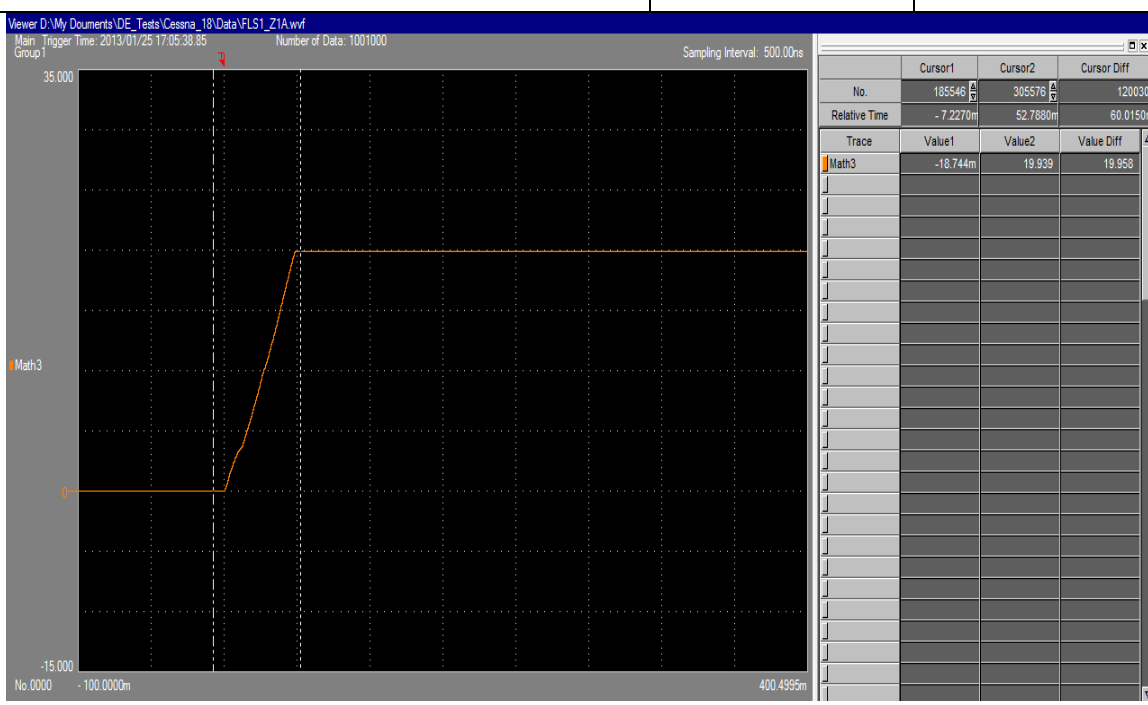


COMPONENT B CHARGE TRANSFER	12.366 Coulombs

Panel: FLS1 – Third Strike (Zone 1A)

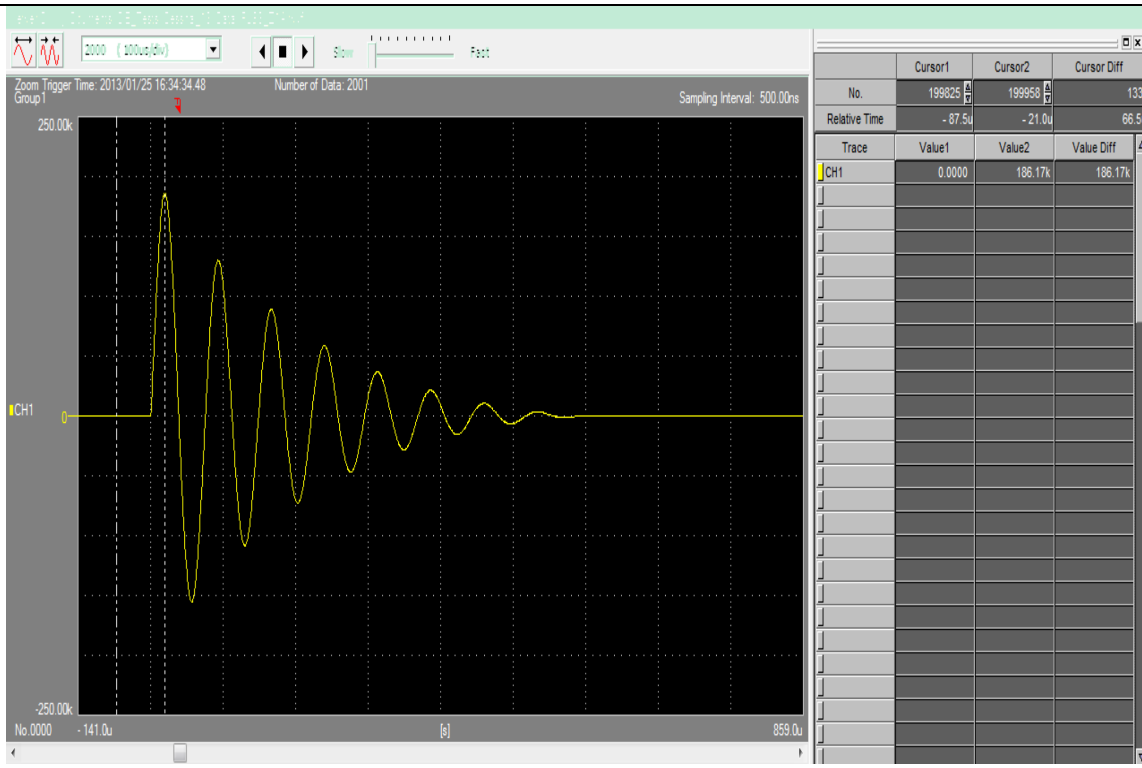


HIGH CURRENT – COMPONENT C*	I_P = 508 Amps	50 mS / Div

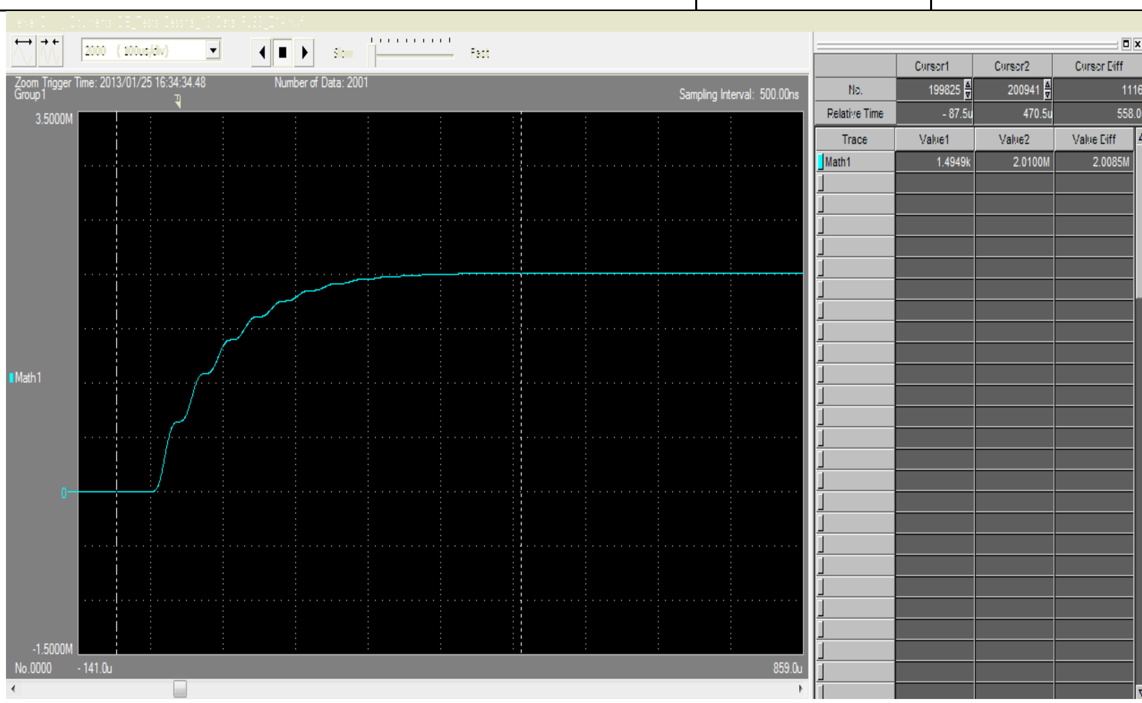


COMPONENT C* CHARGE TRANSFER	20.0 Coulombs

Panel: FLS1 – Third Strike (Zone 1A)

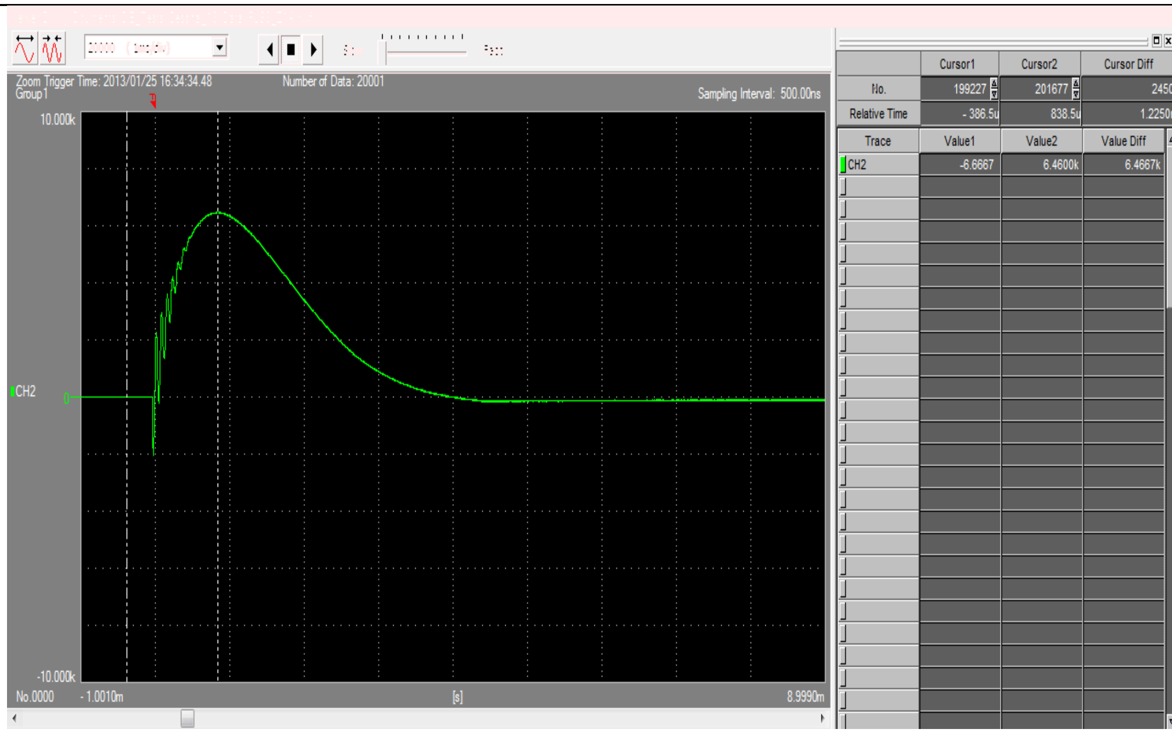


HIGH CURRENT – COMPONENT A	I_P = 186.2 KA	100 uS / Div

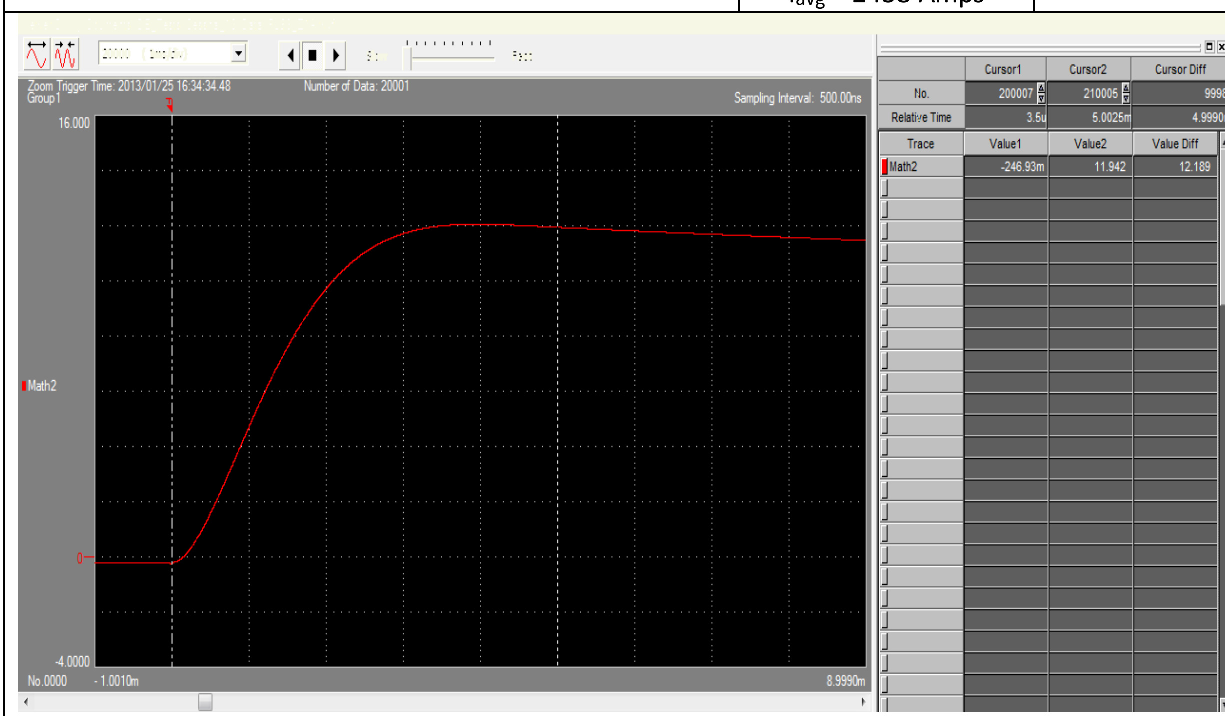


COMPONENT A ACTION INTEGRAL	AI = 2.0085E6 A^2-S

Panel: FLS6 – Third Strike (Zone 1A)

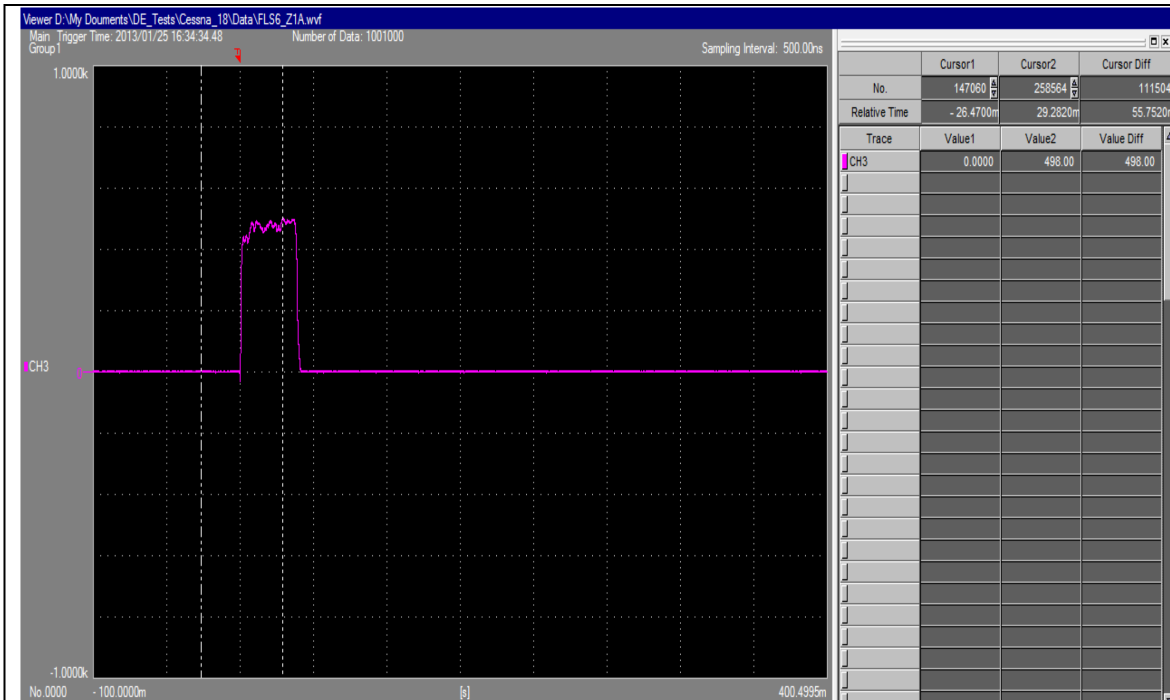


HIGH CURRENT – COMPONENT B	I_P = 6467 Amps I_{avg} = 2438 Amps	1 mS / Div

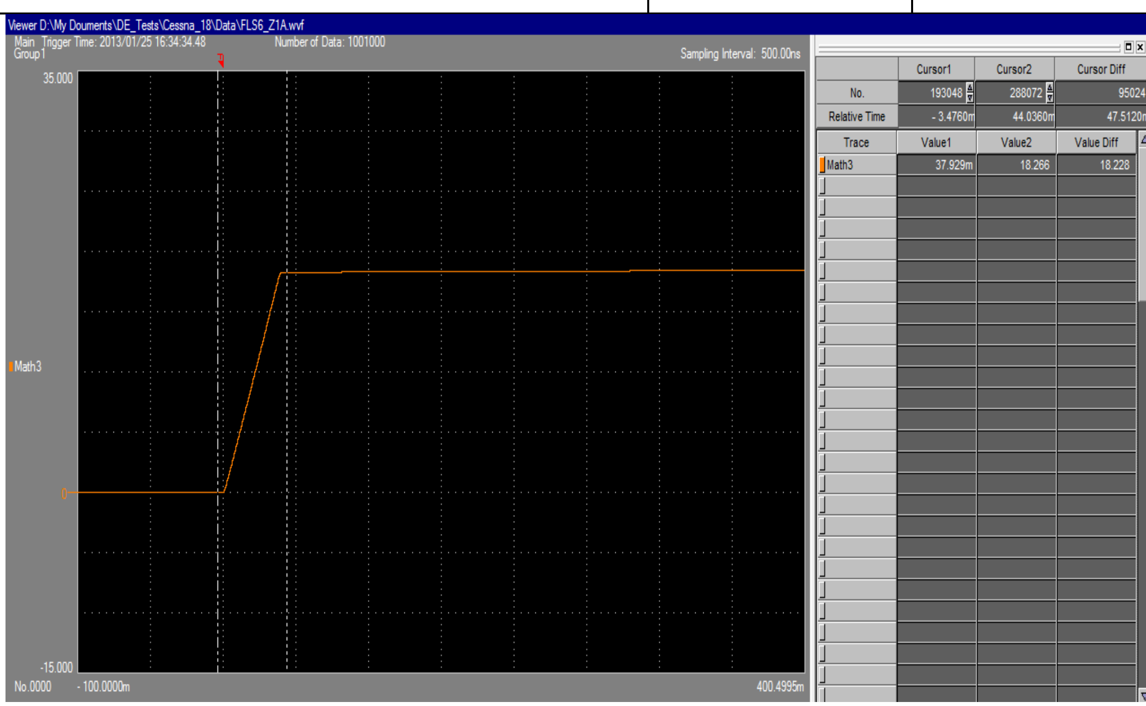


COMPONENT B CHARGE TRANSFER	12.189 Coulombs

Panel: FLS6 – Third Strike (Zone 1A)



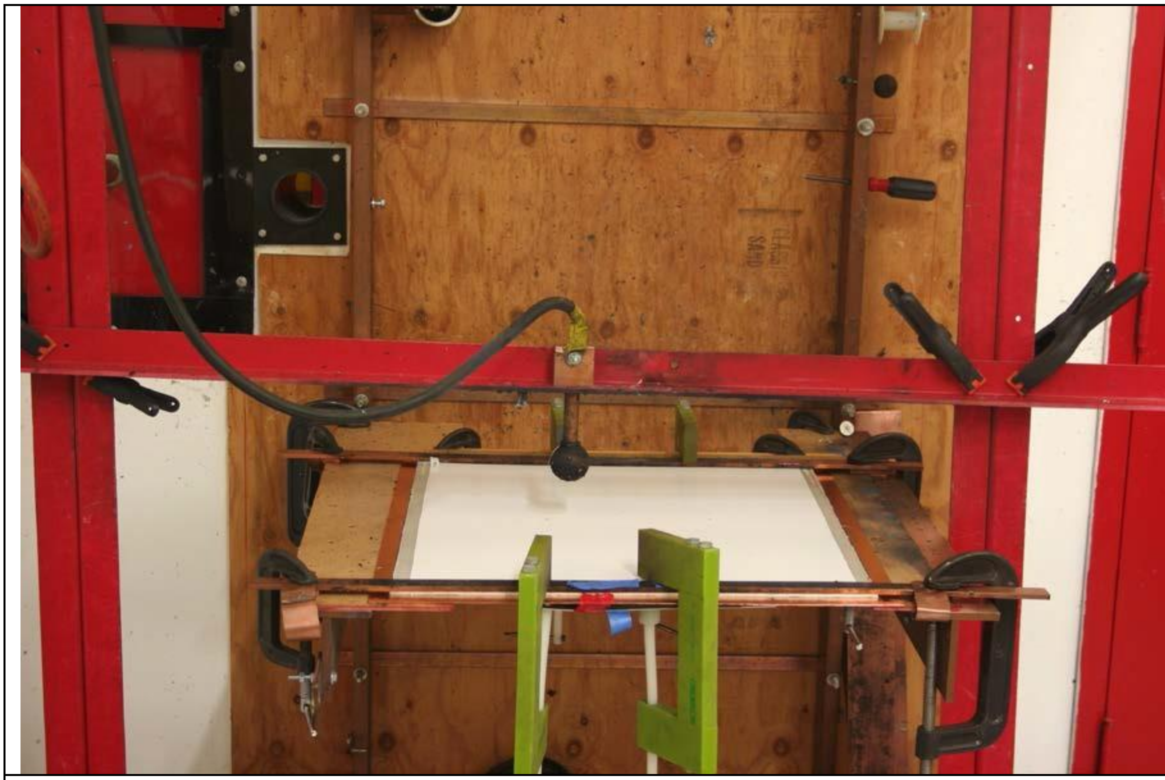
HIGH CURRENT – COMPONENT C*	I_P = 498 Amps	50 mS / Div



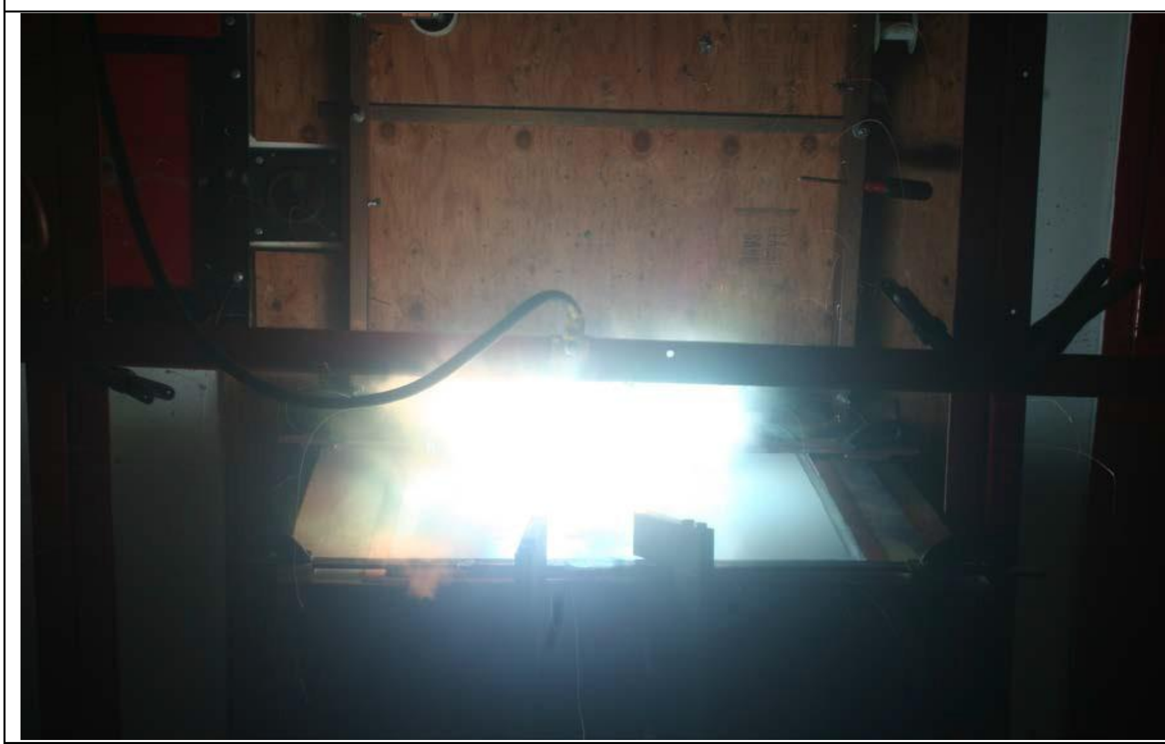
COMPONENT C* CHARGE TRANSFER	18.2 Coulombs

Panel: FLS6 – Third Strike (Zone 1A)

APPENDIX E
Photographs

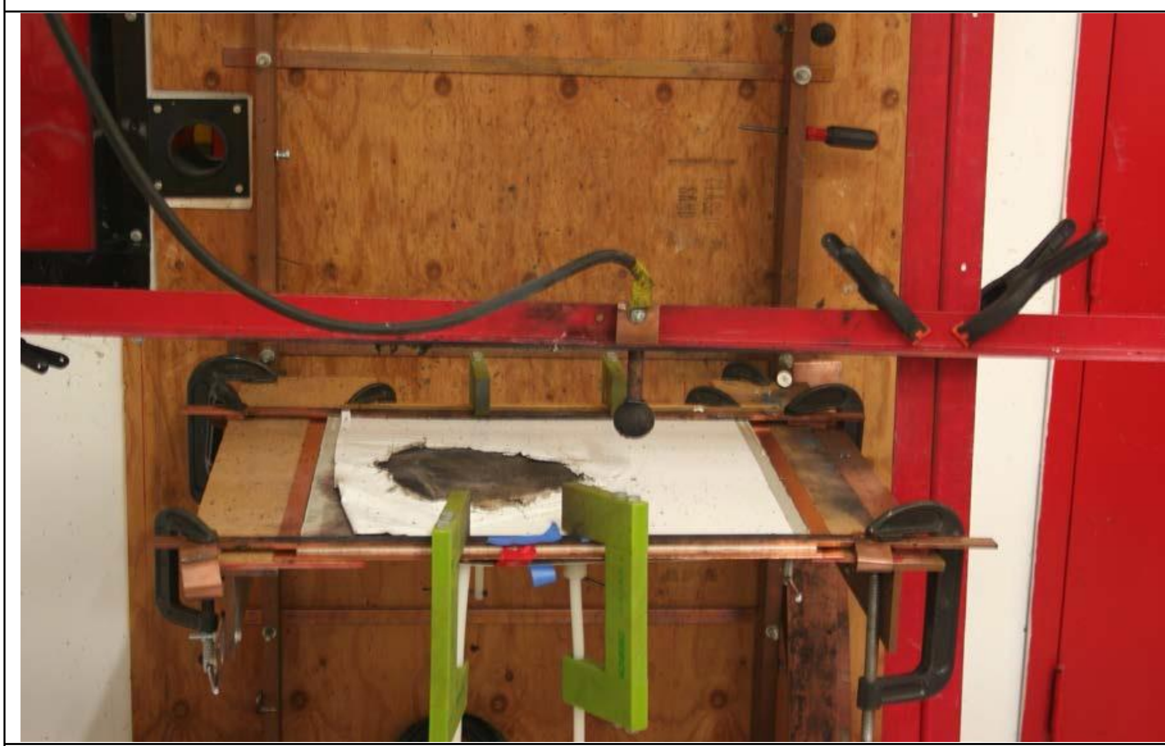


High Current Test – FSL1 – Pre-Strike



High Current Test – FSL1 – Components D, B, C*

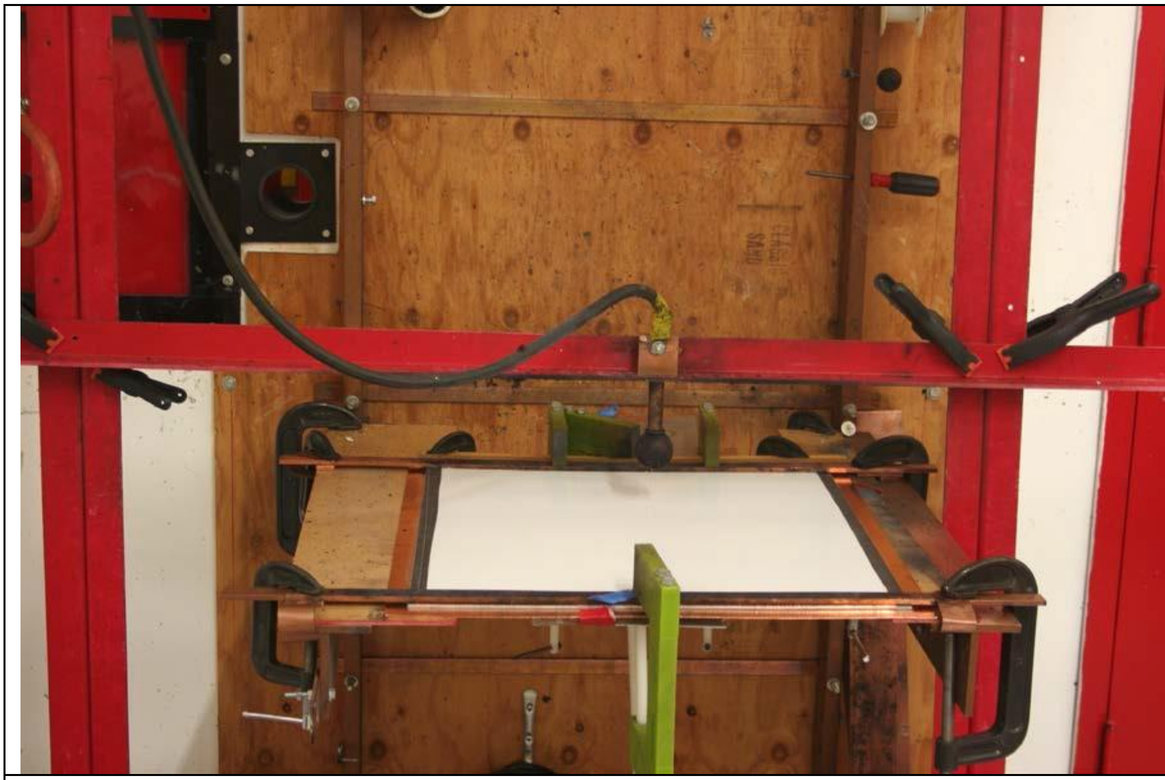
High Current Test – FSL1 – Post-Strike Damage



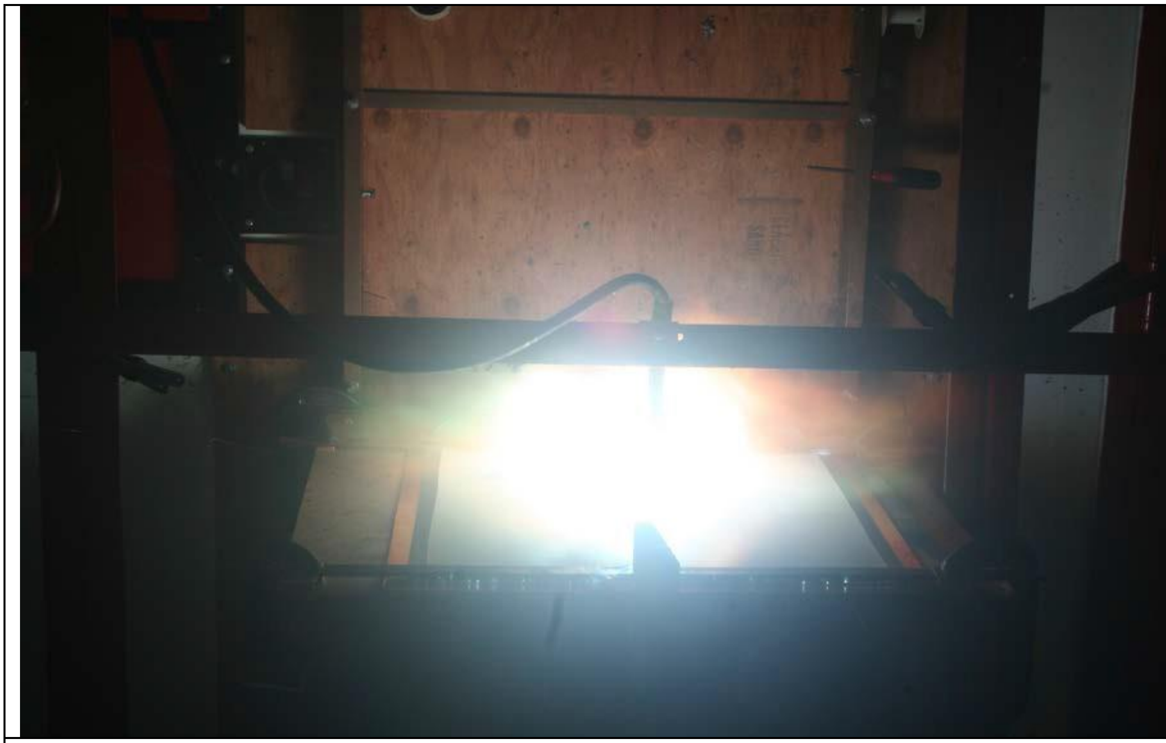
High Current Test – FSL1 – Pre-Strike

High Current Test – FSL1 – Components D, B, C*

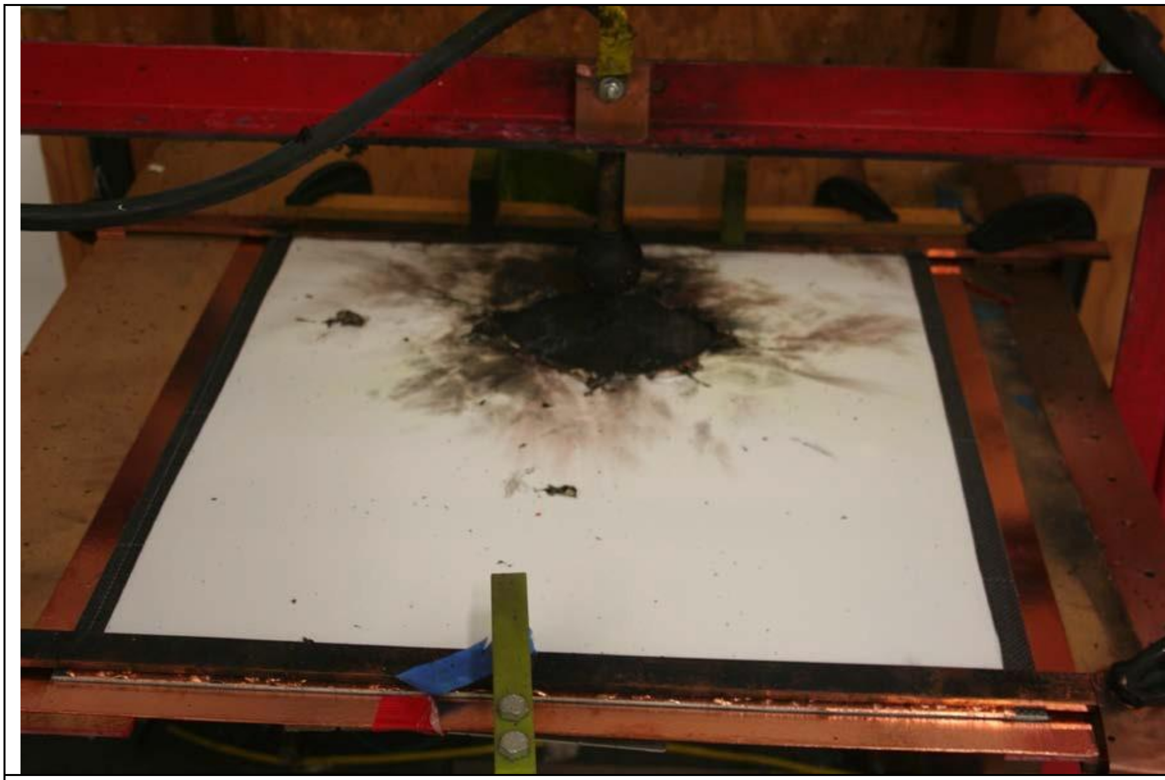
High Current Test – FSL1 – Post-Strike Damage



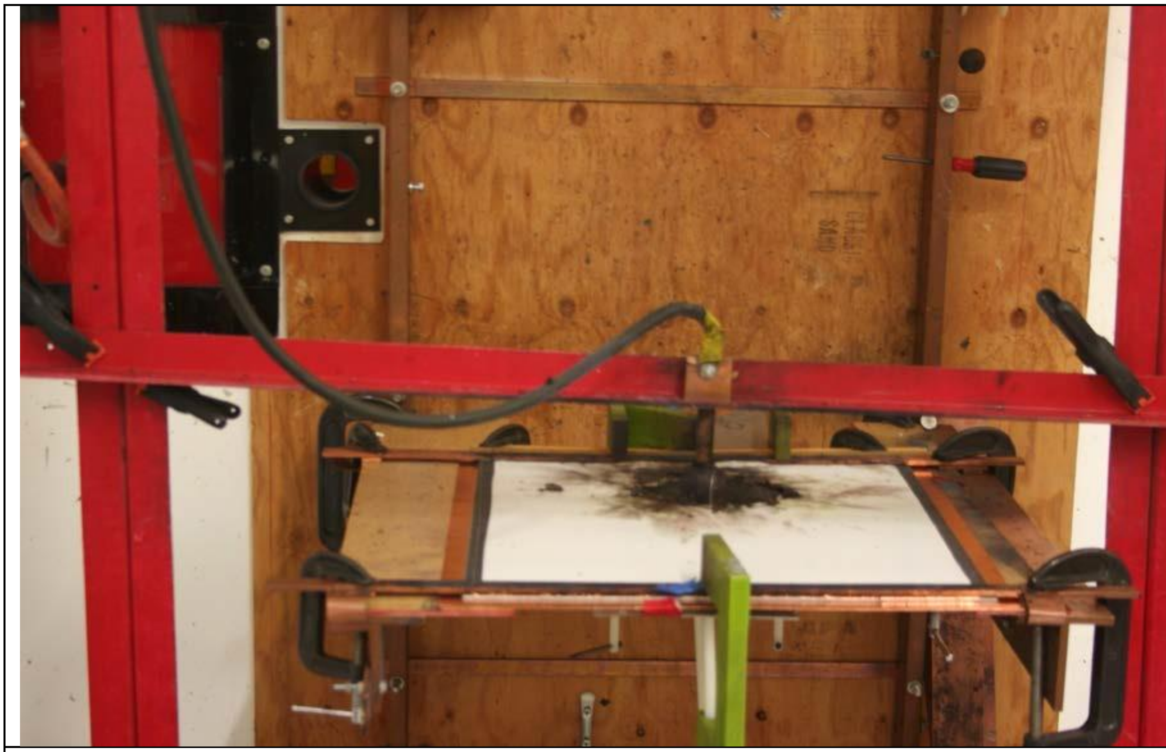
High Current Test – FSL2 – Pre-Strike



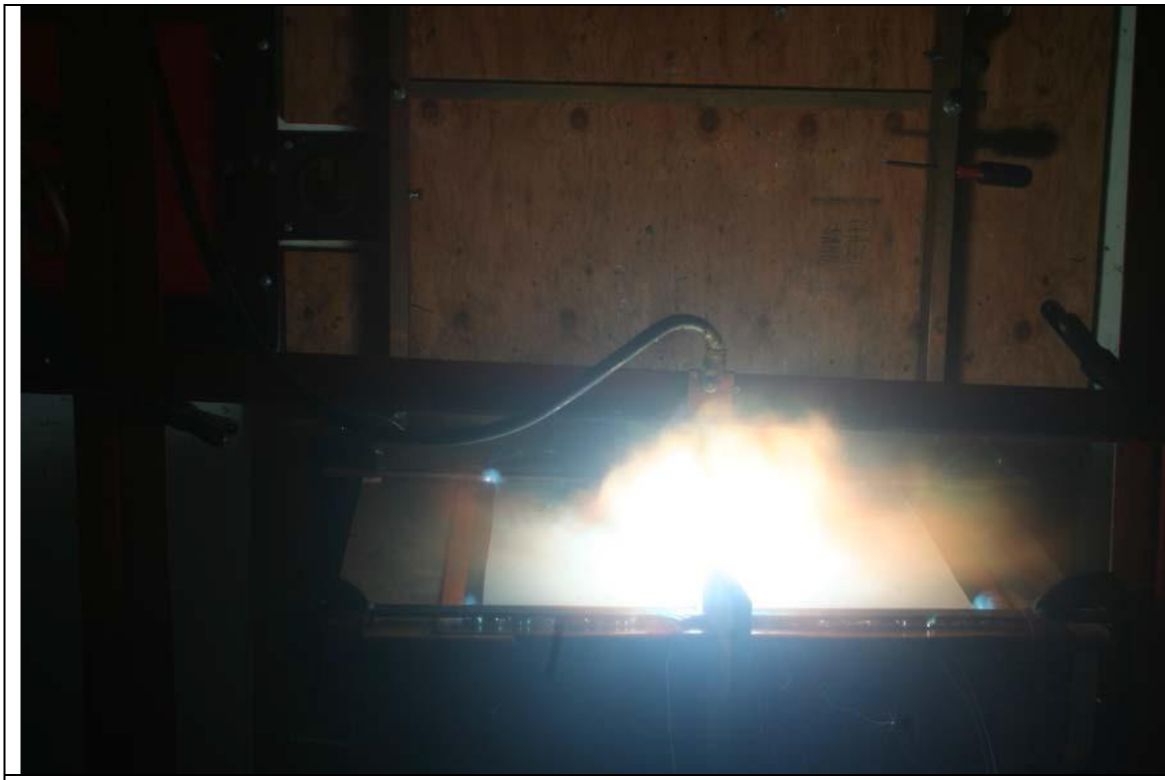
High Current Test – FSL2 – Components D, B, C*



High Current Test – FSL2 – Post-Strike Damage



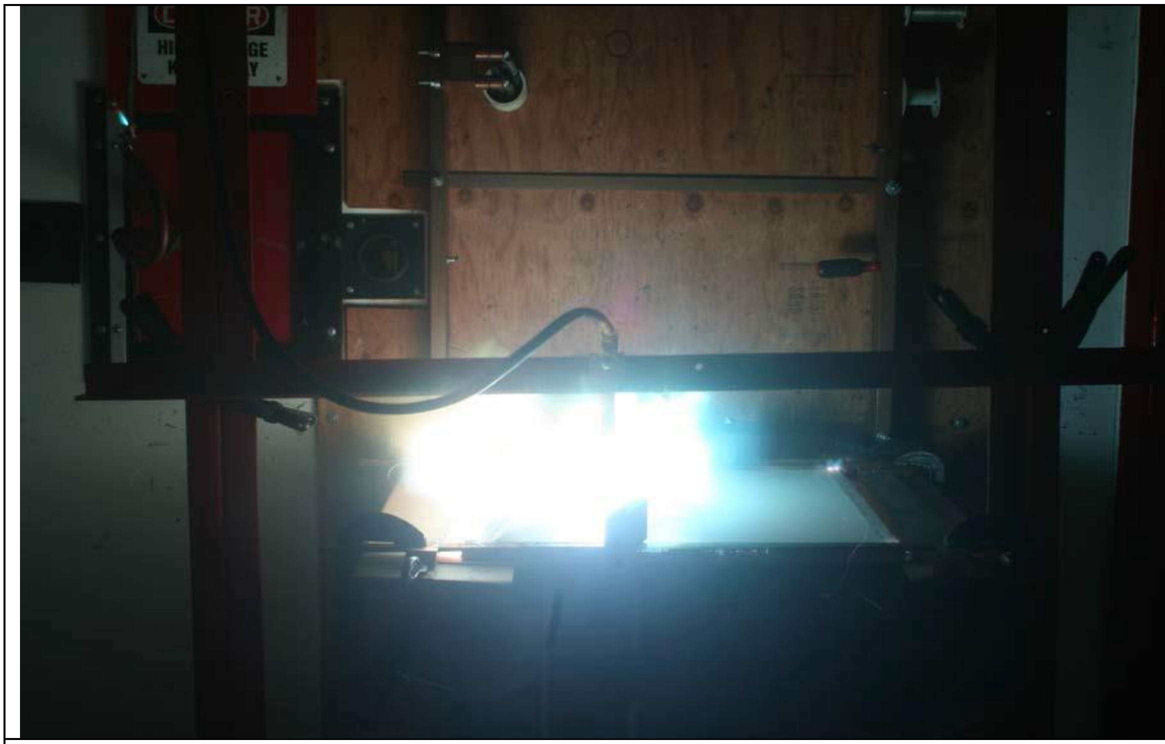
High Current Test – FSL2 – Pre-Strike



High Current Test – FSL2 – Components D, B, C*

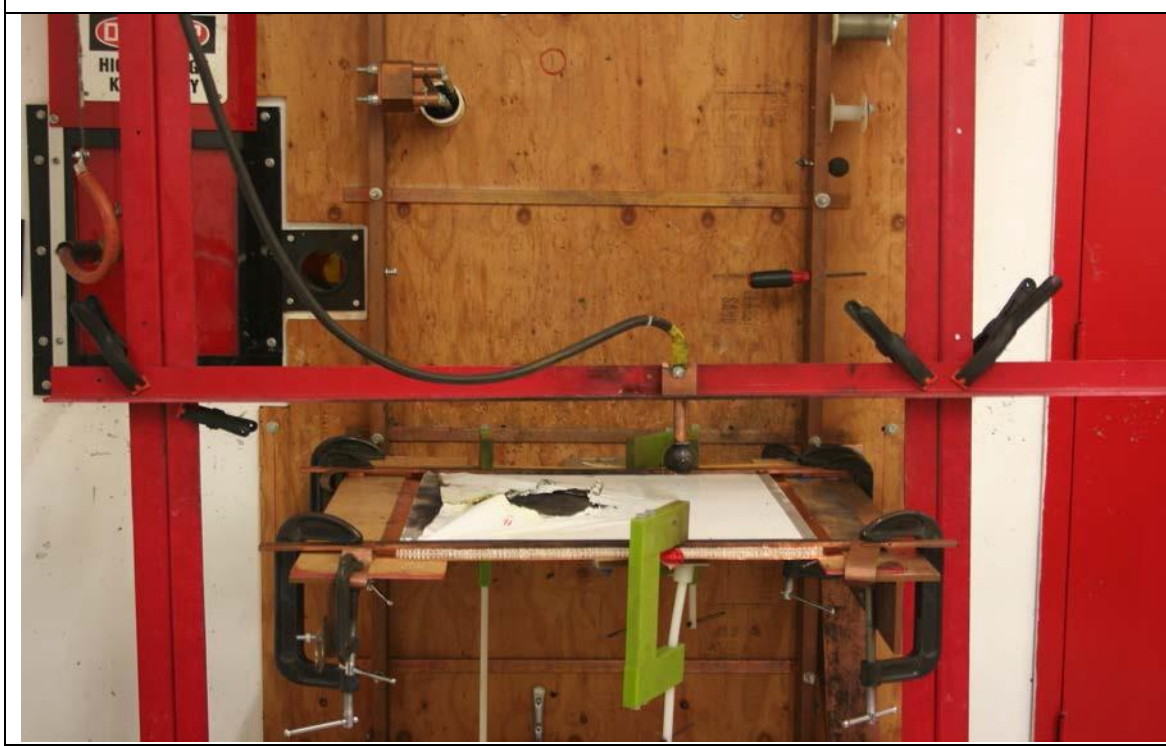
High Current Test – FSL2 – Post-Strike Damage

High Current Test – FSL3 – Pre-Strike

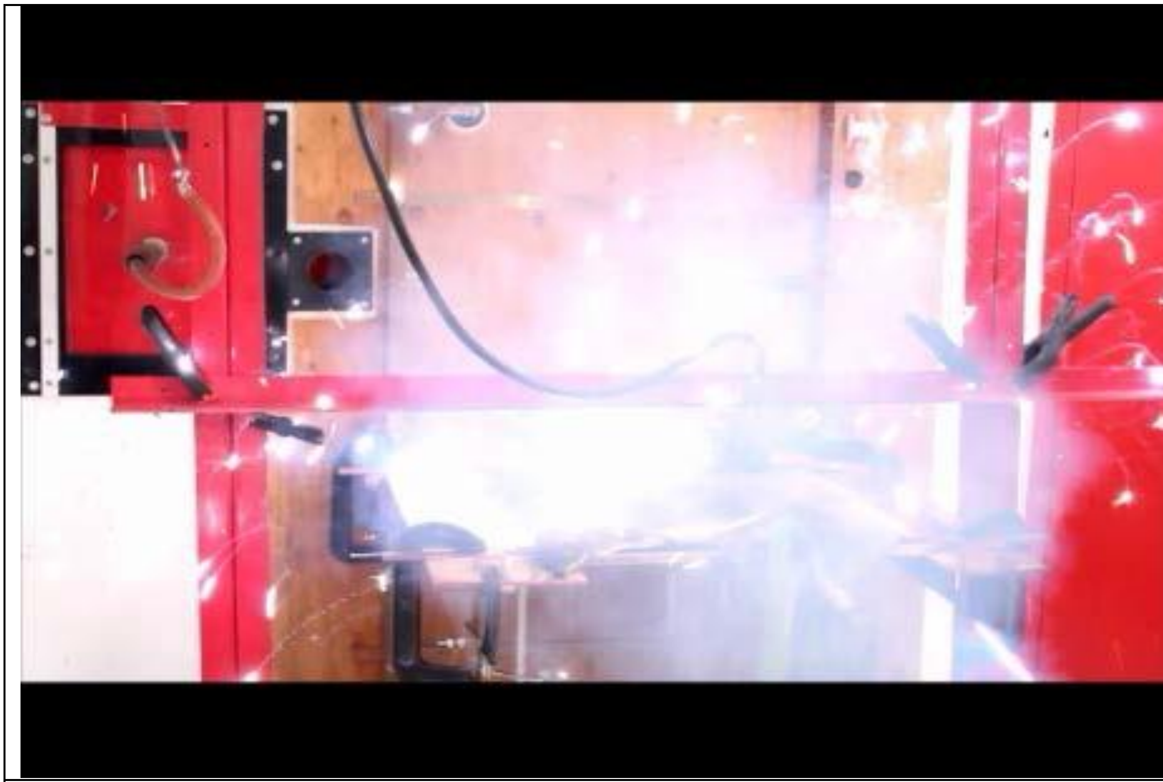


High Current Test – FSL3 – Components D, B, C*

High Current Test – FSL3 – Post-Strike Damage

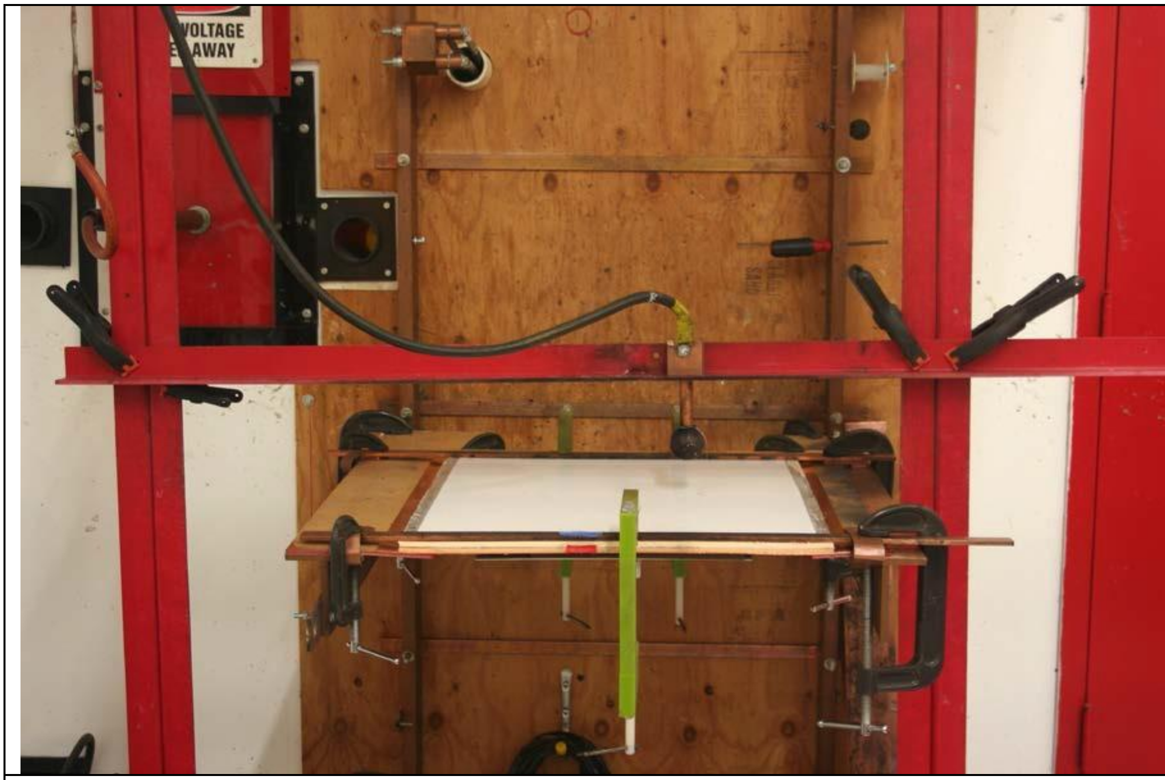


High Current Test – FSL3 – Pre-Strike

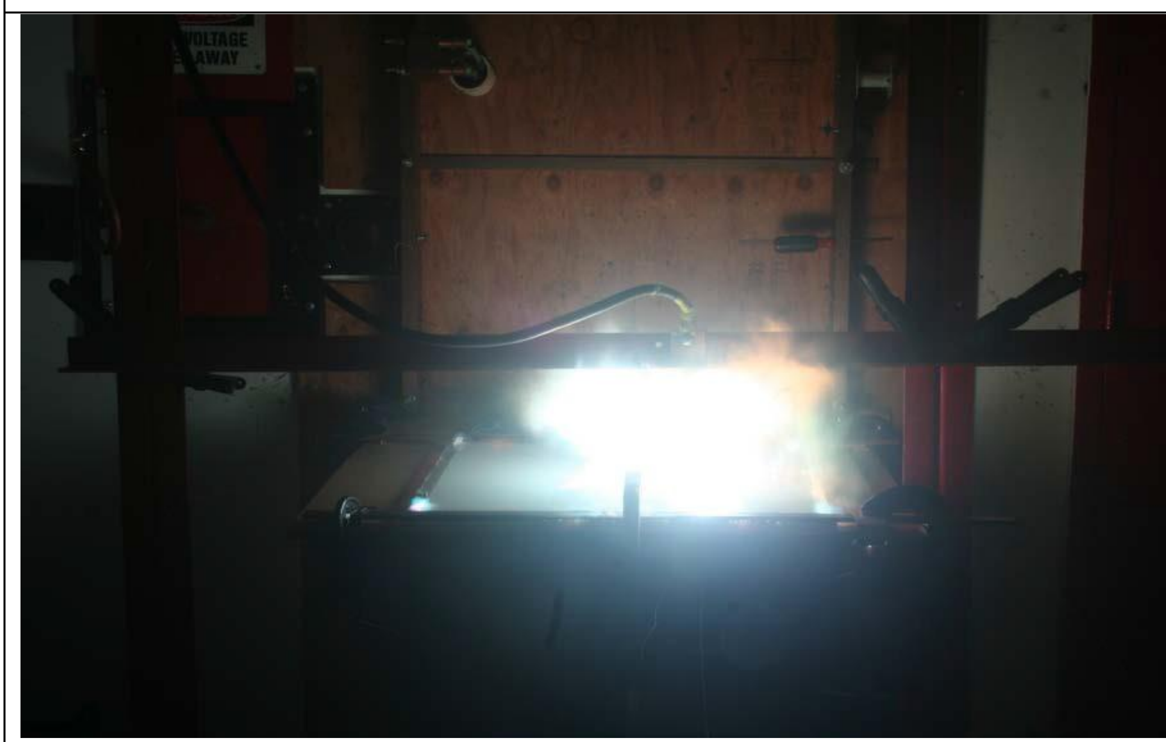


High Current Test – FSL3 – Components D, B, C*

High Current Test – FSL3 – Post-Strike Damage

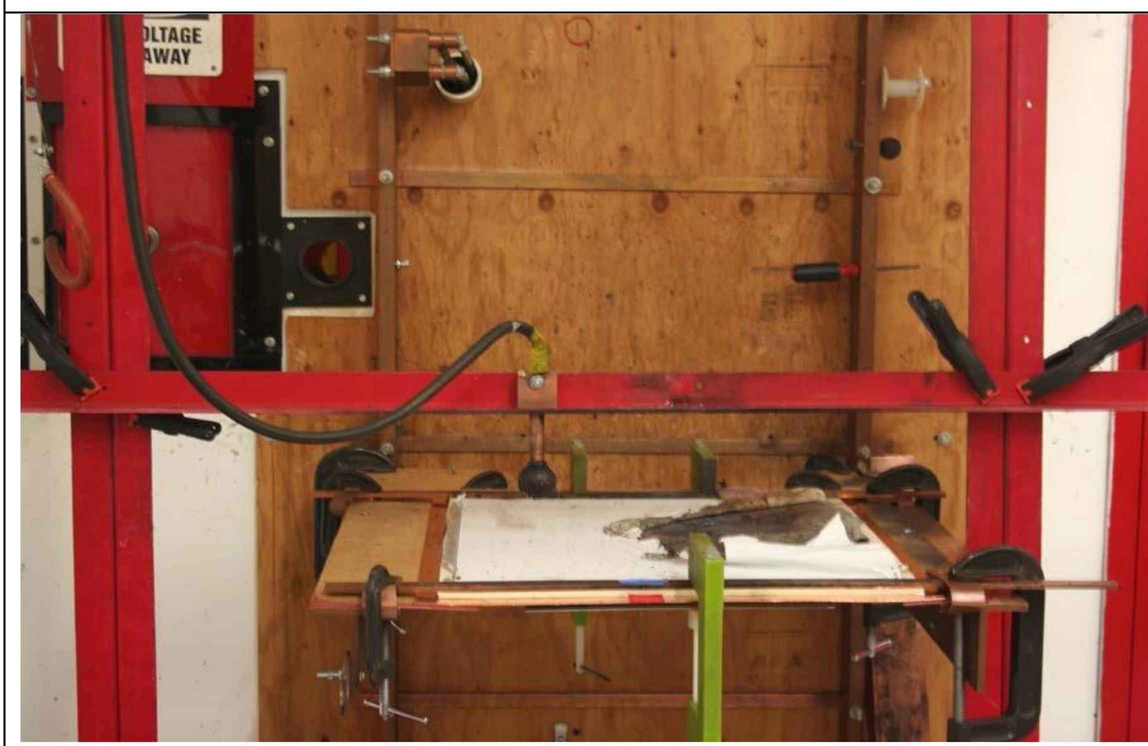


High Current Test – FSL4 – Pre-Strike

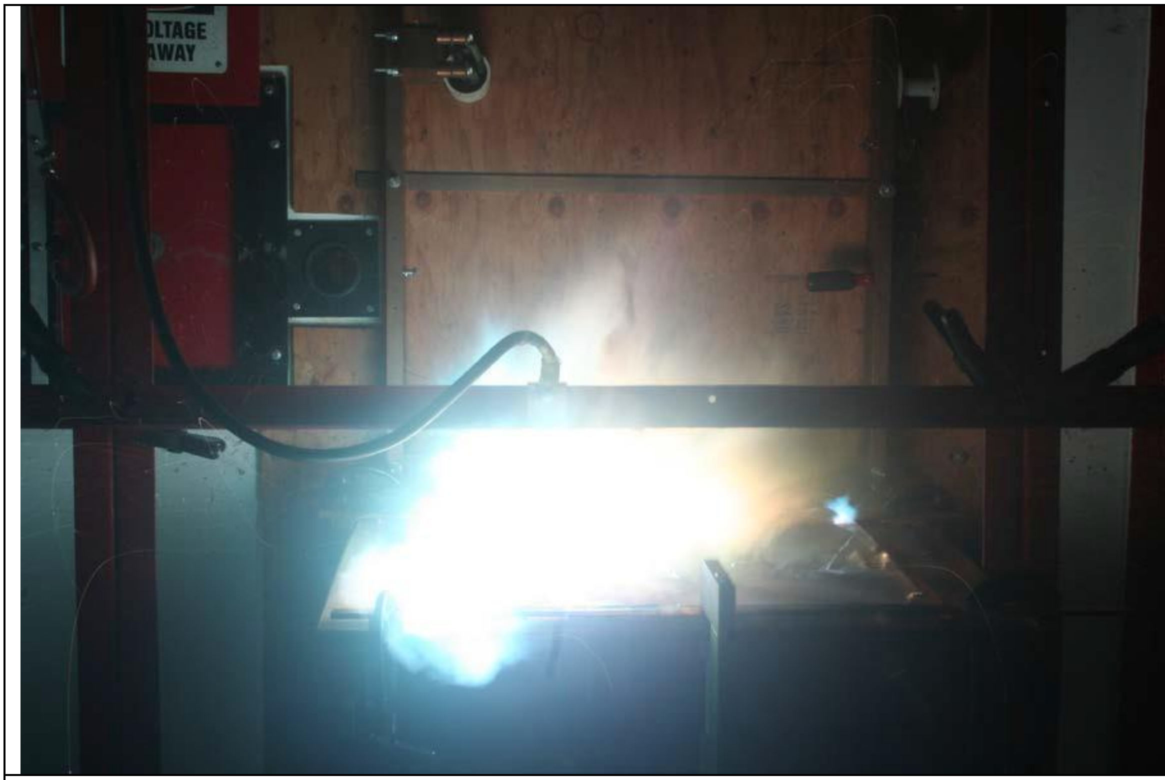


High Current Test – FSL4 – Components D, B, C*

High Current Test – FSL4 – Post-Strike Damage

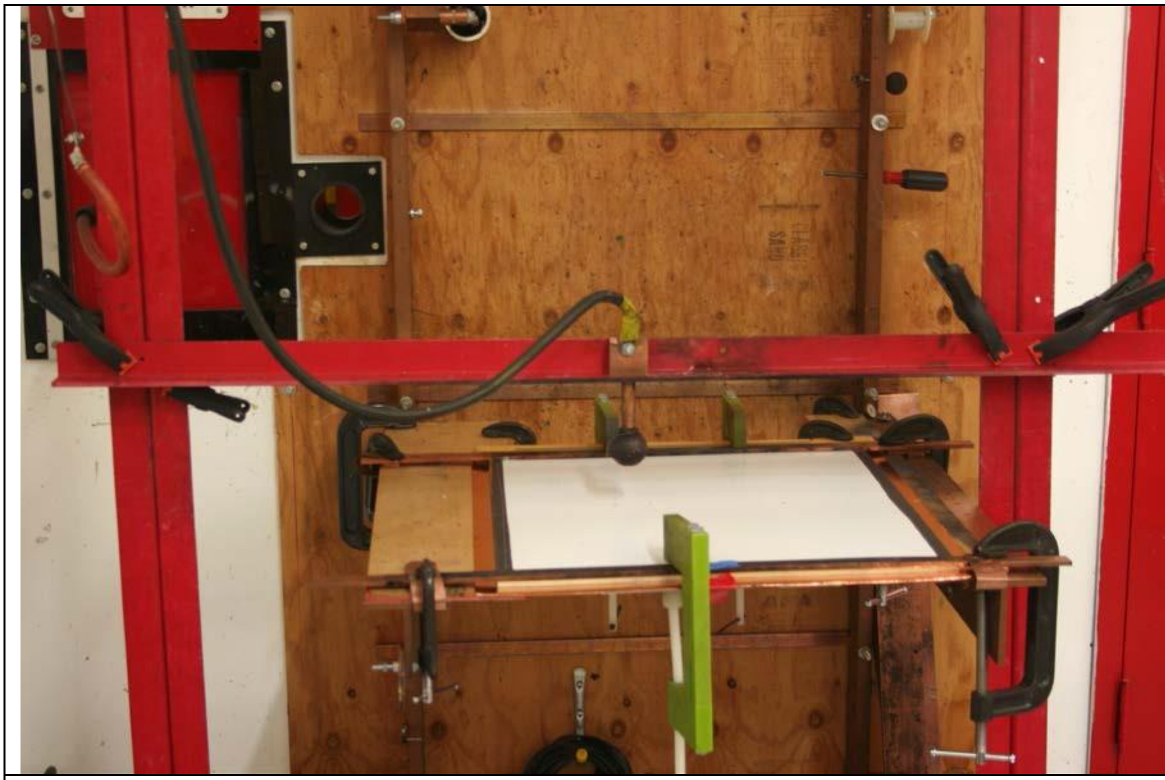


High Current Test – FSL4 – Pre-Strike

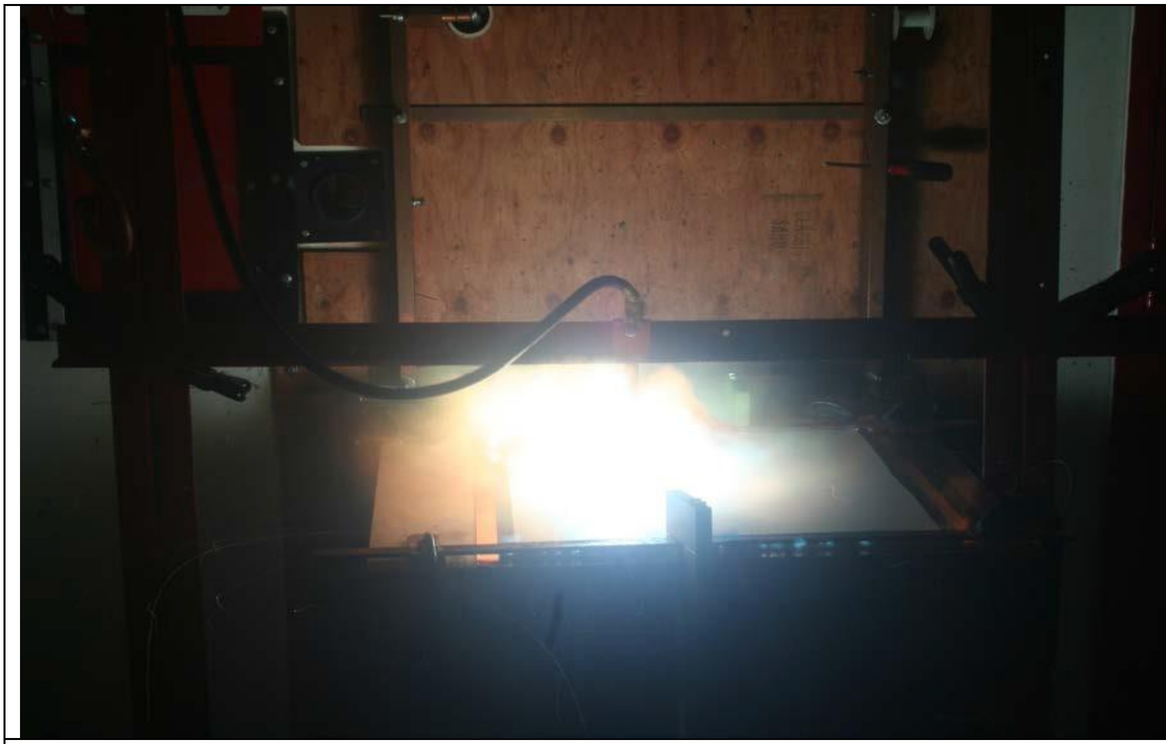


High Current Test – FSL4 – Components D, B, C*

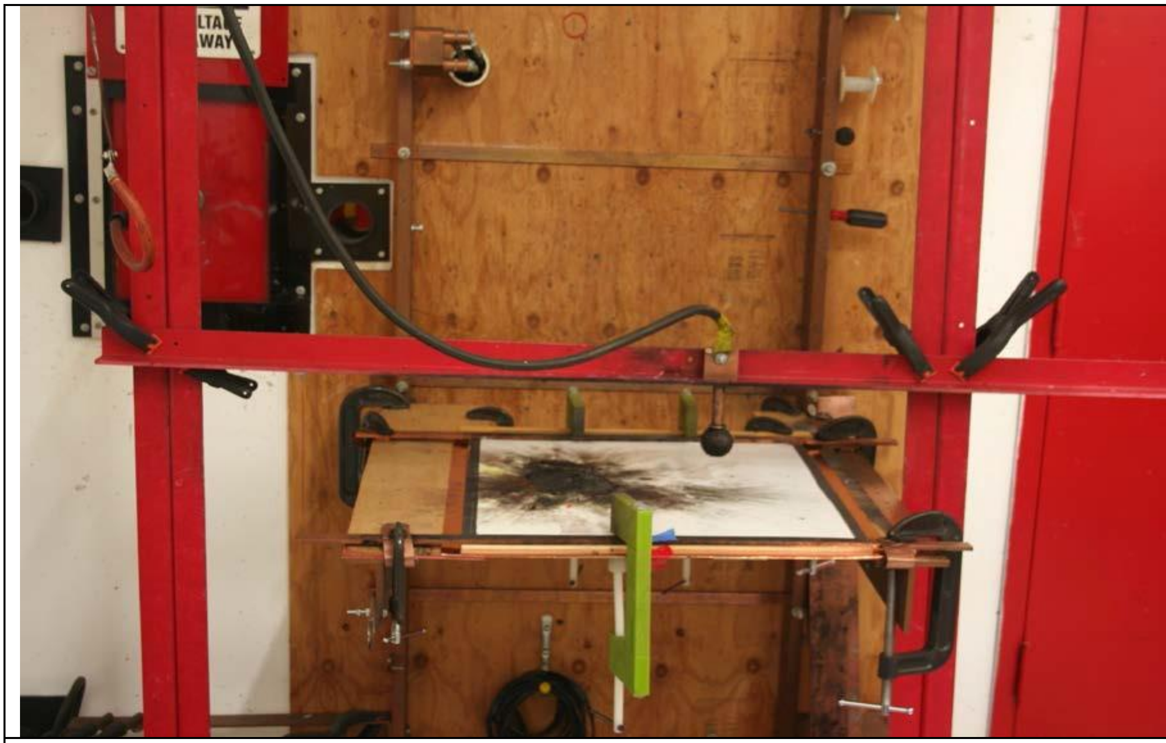
High Current Test – FSL4 – Post-Strike Damage



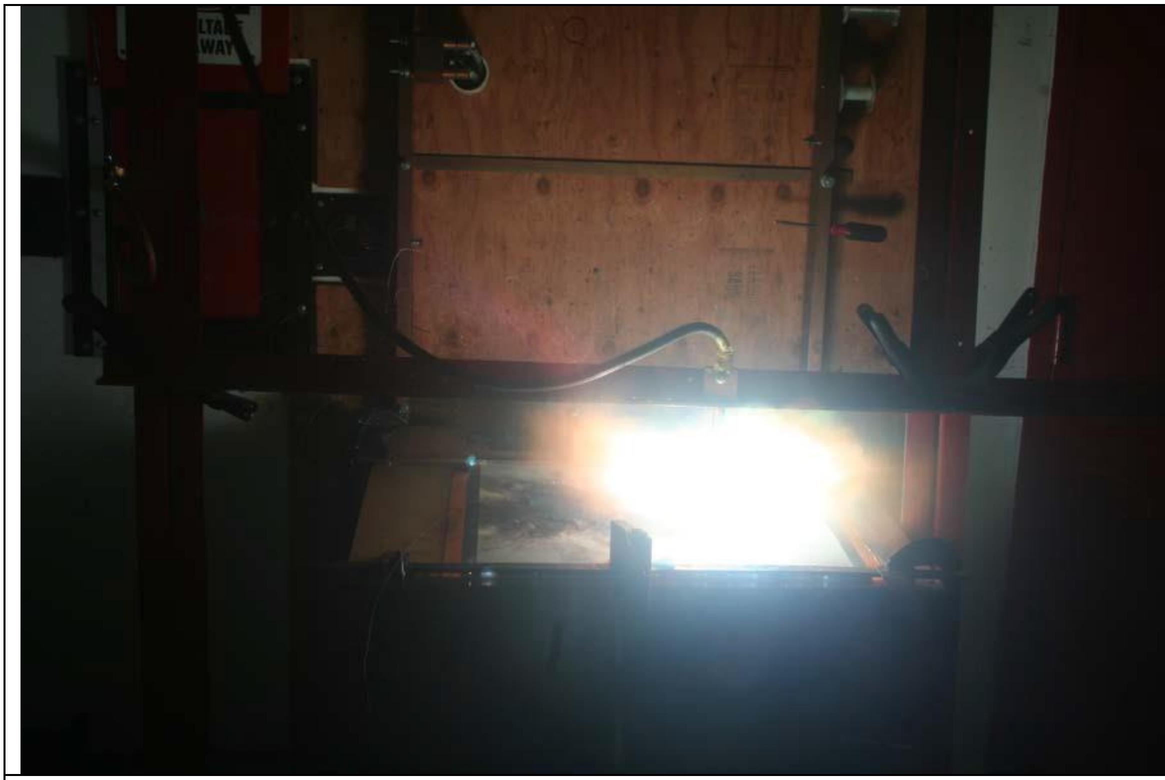
High Current Test – FSL5 – Pre-Strike


High Current Test – FSL5 – Components D, B, C*

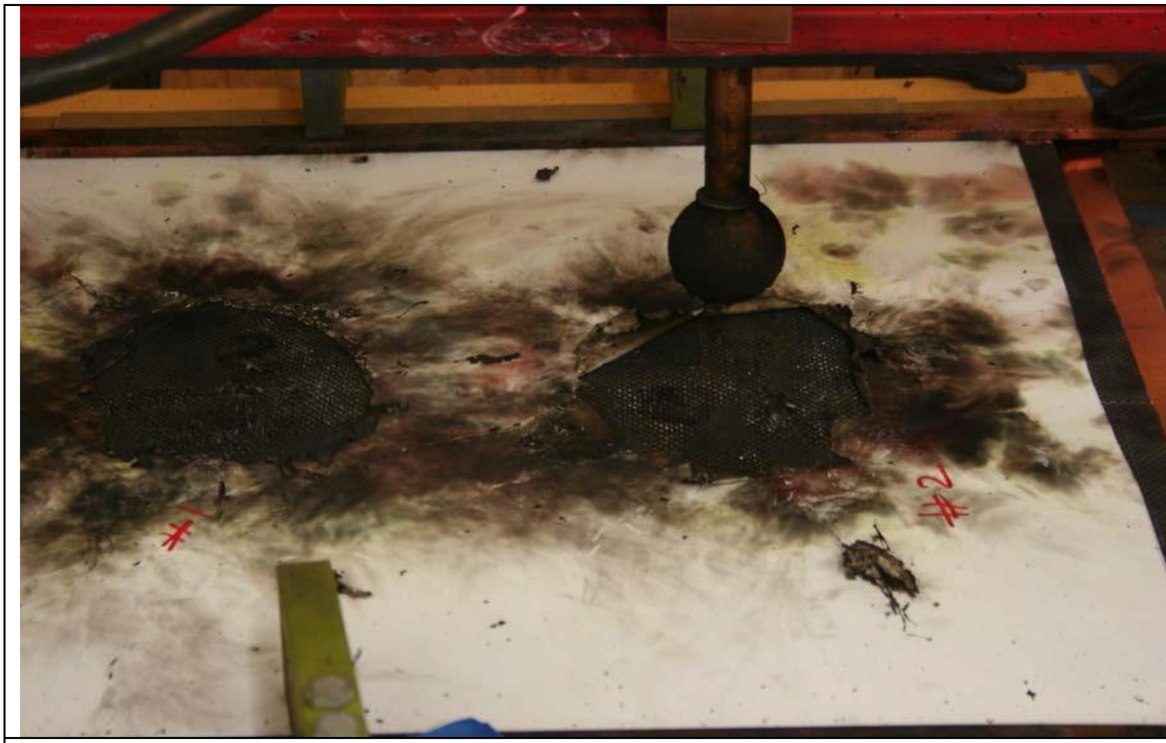
High Current Test – FSL5 – Post-Strike Damage



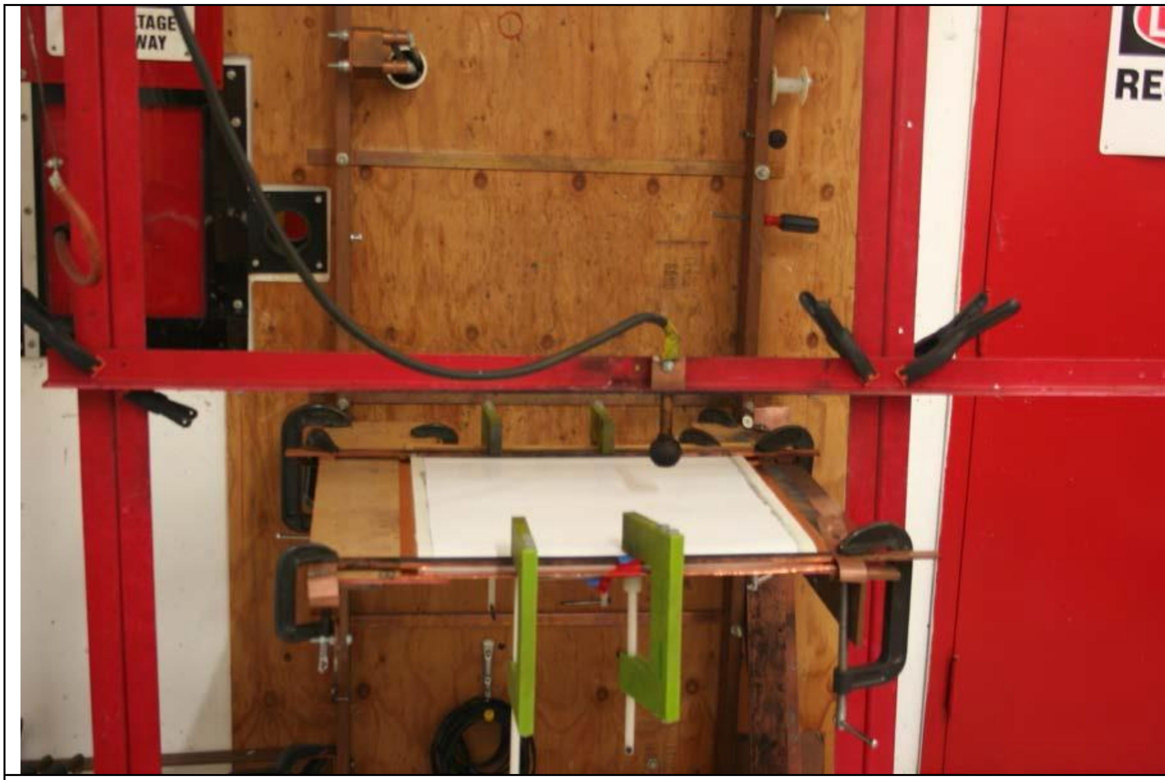
High Current Test – FSL5 – Pre-Strike



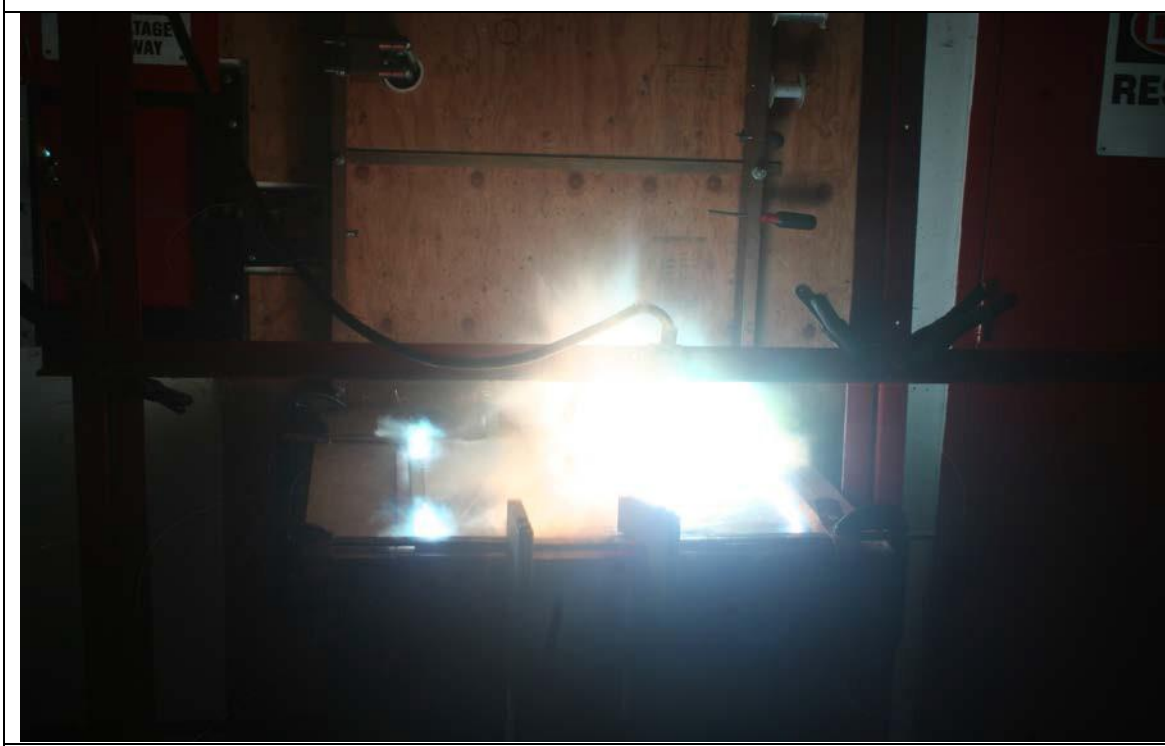
High Current Test – FSL5 – Components D, B, C*



High Current Test – FSL5 – Post-Strike Damage



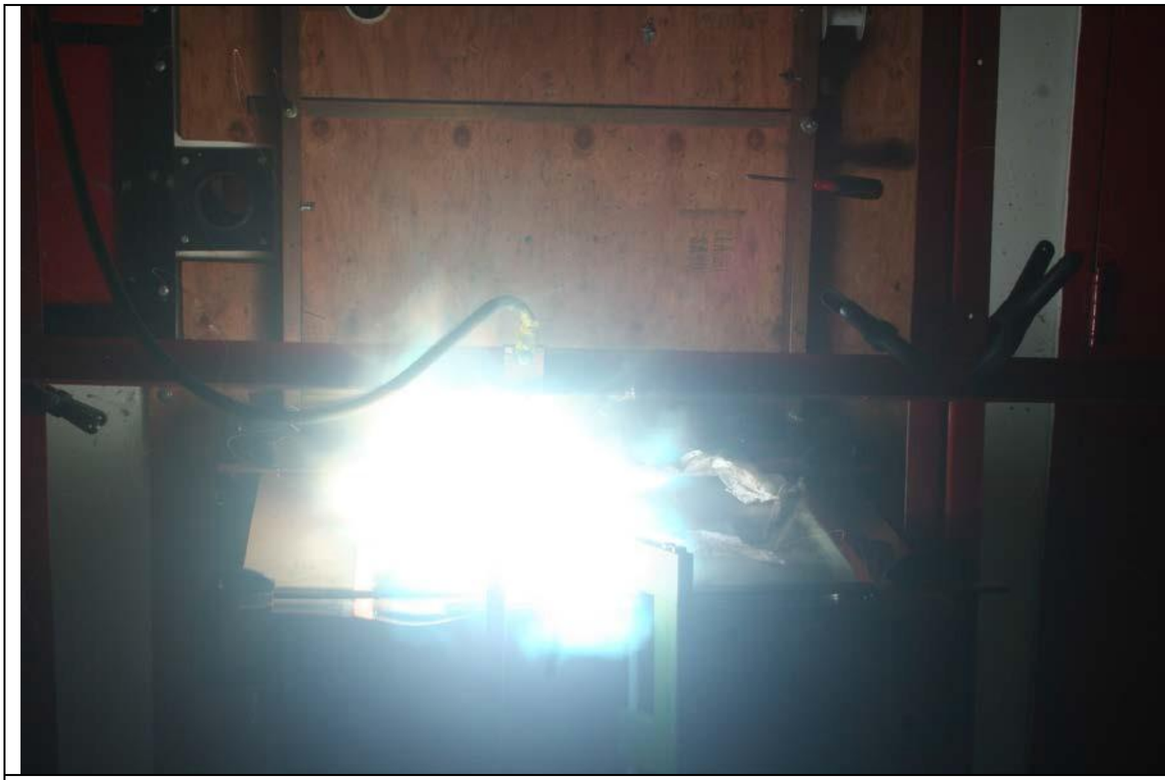
High Current Test – FSL6 – Pre-Strike



High Current Test – FSL6 – Components D, B, C*

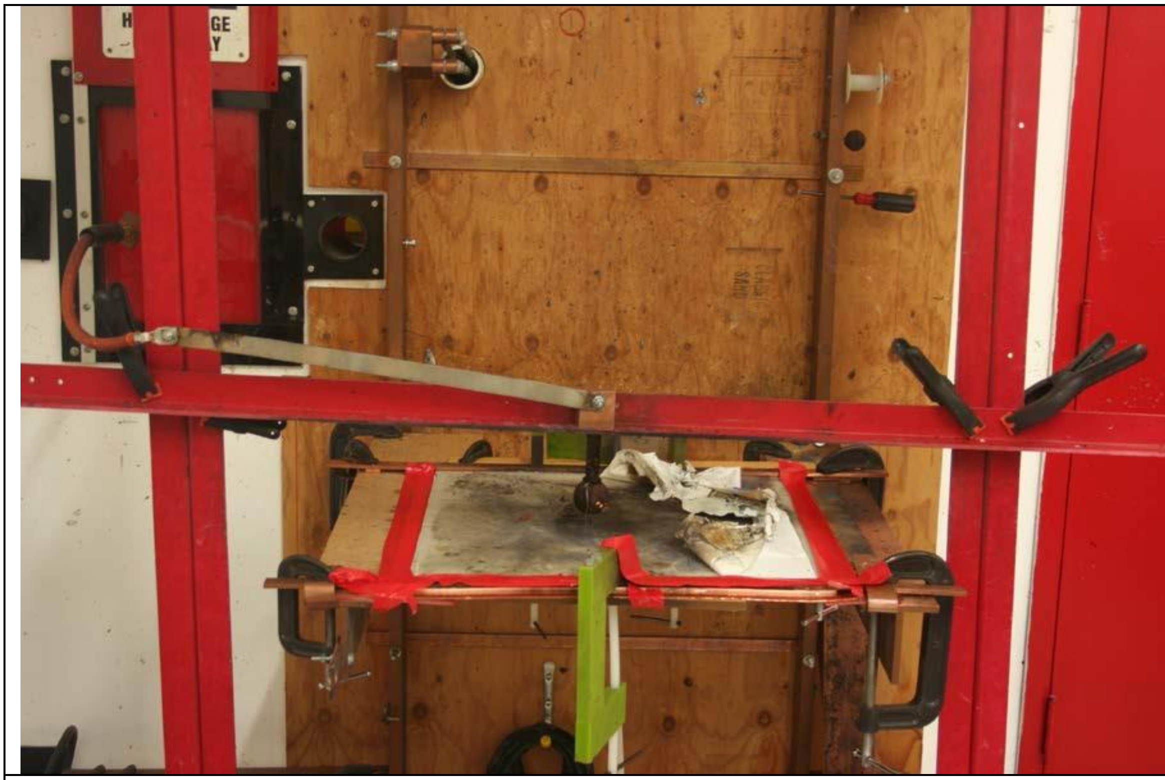
High Current Test – FSL6 – Post-Strike Damage

High Current Test – FSL6 – Pre-Strike



High Current Test – FSL6 – Components D, B, C*

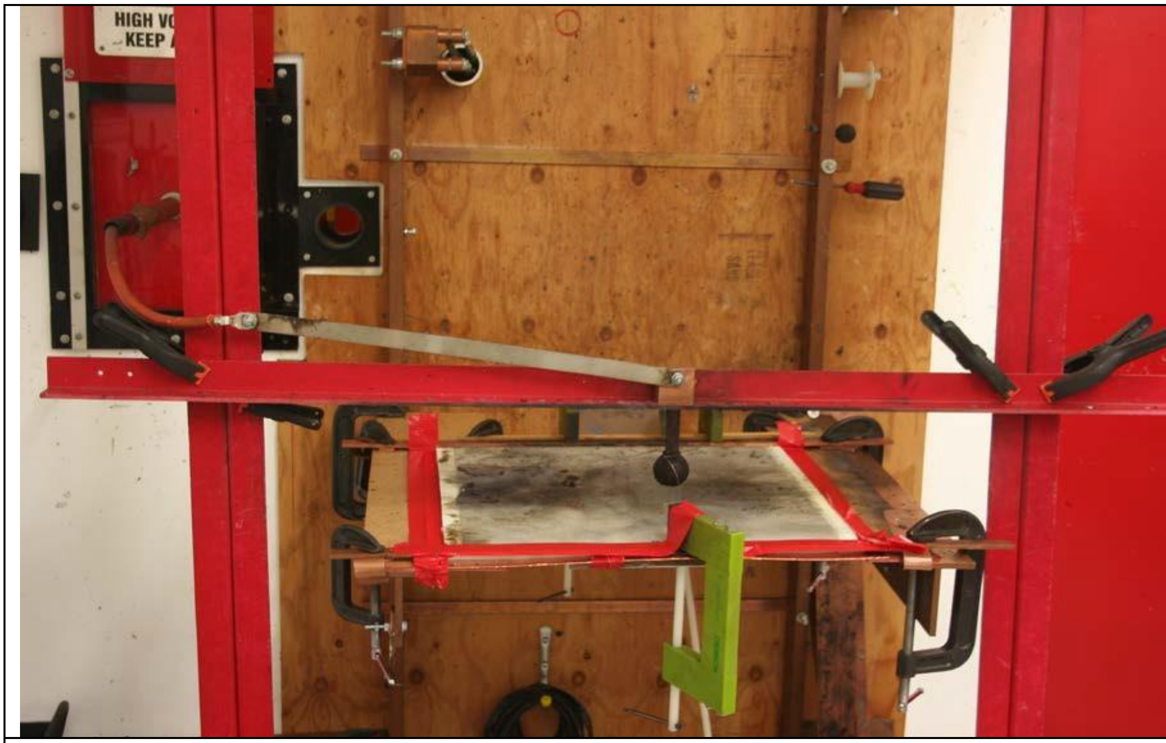
High Current Test – FSL6 – Post-Strike Damage



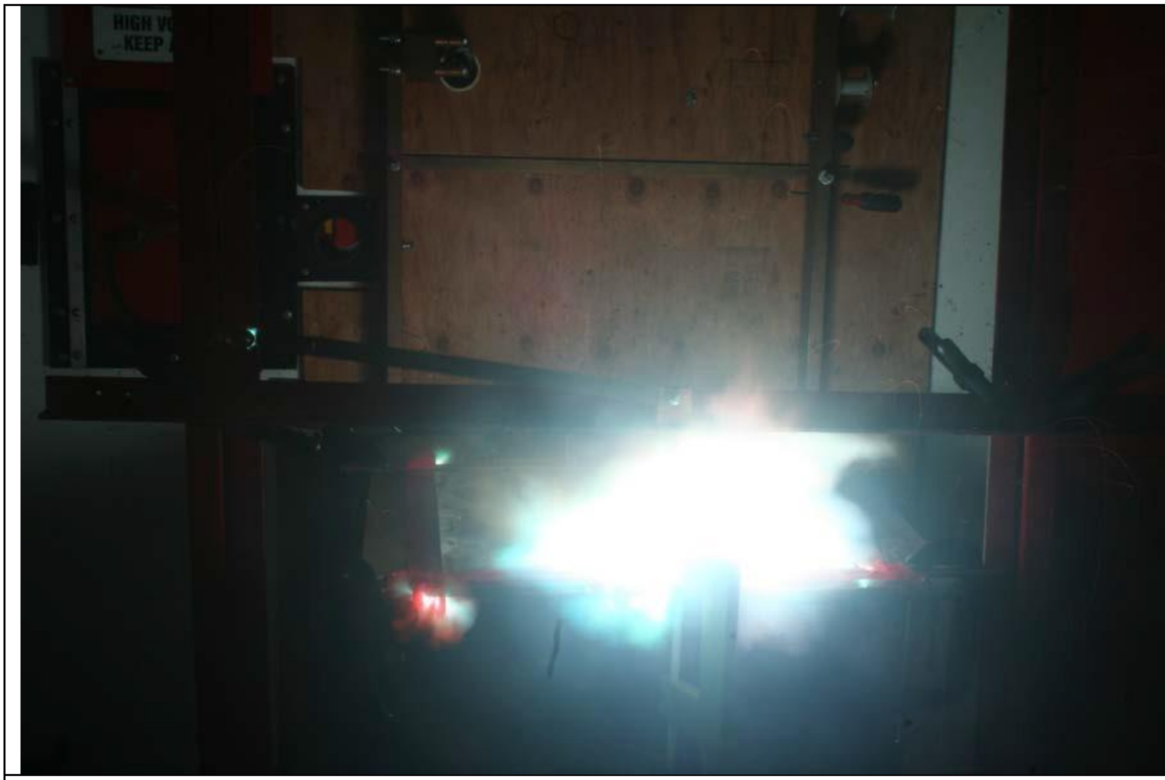
High Current Test – FSL1 – Pre-Strike (Zone 1A)

High Current Test – FSL1 – Components A, B, C*

High Current Test – FSL1 – Post-Strike Damage



High Current Test – FSL6 – Pre-Strike (Zone 1A)



High Current Test – FSL6 – Components A, B, C*

No Photo

High Current Test – FSL6 – Post-Strike Damage

END OF REPORT

SIZE	CAGE CODE	DRAWING NO.
A	63242	TR057111
SCALE: NONE	REV LTR -	FINAL SHEET

Appendix M
Acoustic Test Data Uncertainty

Table M-1 - TL Uncertainty (1 of 3)

1/3 Octave Frequency (Hz)	FAC-6a (+/- dB)	Notes	FAC-6b (+/- dB)	Notes	FAC-6c (+/- dB)	Notes	FAC-6d (+/- dB)	Notes
50		[c][f]		[c][f]		[d][f]		[c][f]
63		[d][f]		[d][f]		[d][f]		[d][f]
80	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]
100	2.1		2.1		2.1		2.1	
125	1.9		1.8		1.9		1.8	
160	2.0		2.0		2.0		2.0	
200	0.9		0.9		0.9		1.0	
250	0.4		0.5		0.5		0.5	
315	0.6		0.4		0.4		0.5	
400	0.3		0.3		0.3		0.3	
500	0.4		0.4		0.4		0.4	
630	0.3		0.3		0.3		0.3	
800	0.3		0.3		0.3	[c]	0.3	
1000	0.2		0.2		0.2	[c]	0.2	
1250	0.2		0.2		0.2	[c]	0.2	
1600	0.2		0.2		0.2	[c]	0.2	[c]
2000	0.2		0.2	[c]	0.2	[d]	0.2	[d]
2500	0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]
3150	0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]
4000	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
5000	0.2	[d]	0.2	[d]	0.2	[d]	0.3	[d]
6300	0.3	[d]	0.3	[d]	0.2	[d]	0.3	[d]
8000	0.4	[d]	0.3	[d]	0.3	[d]	0.3	[d]
10000	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]

Table M-2 - TL Uncertainty (2 of 3)

1/3 Octave Frequency (Hz)	FAC-1 (+/- dB)	Notes	FAC-2 (+/- dB)	Notes	FAC-3 (+/- dB)	Notes	FAC-4 (+/- dB)	Notes	FAC-5 (+/- dB)	Notes	FAC-7 (+/- dB)	Notes	FAC-8 (+/- dB)	Notes
50		[d][f]		[d][f]		[c][f]		[d][f]		[c][f]		[c][f]		[c][f]
63		[b][d][f]		[b][d][f]		[d][f]		[b][d][f]		[b][d][f]		[c][f]		[d][f]
80	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]
100	2.1		2.1		2.1		2.1		2.1		2.1		2.1	
125	1.9		1.9		1.8		1.9		1.8		1.9		1.9	
160	2.0		2.0		2.0		2.0		2.0		2.0		2.0	
200	0.9		0.9		0.9		0.8		0.9		0.8		0.9	
250	0.5		0.4		0.5		0.4		0.4		0.6		0.4	
315	0.5		0.4		0.5		0.4		0.4		0.5		0.4	
400	0.3		0.3		0.3		0.3		0.3		0.4		0.3	
500	0.3		0.4		0.4		0.4		0.4		0.4		0.3	
630	0.3		0.3		0.3		0.3		0.3		0.3		0.3	
800	0.3		0.3		0.3		0.3		0.3		0.3		0.3	
1000	0.2		0.2		0.2		0.2		0.3		0.2		0.2	
1250	0.2		0.2		0.2		0.2		0.2		0.2		0.2	
1600	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2		0.2		0.2	
2000	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.3	[c]	0.2		0.2	
2500	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.3		0.2	
3150	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2		0.2	
4000	0.2	[c]	0.2	[c]	0.2	[c]	0.2		0.2	[c]	0.2		0.2	
5000	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]	0.2		0.2	
6300	0.2	[c]	0.2	[c]	0.2	[c]	0.3	[c]	0.2	[c]	0.3	[c]	0.3	[c]
8000	0.3	[d]	0.3	[d]	0.3	[d]	0.3	[d]	0.3	[d]	0.4	[c]	0.3	[c]
10000	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[c]	0.5	[c]

Table M-3 - TL Uncertainty (3 of 3)

1/3 Octave Frequency (Hz)	FAC-9a (+/- dB)	Notes	FAC-9b (+/- dB)	Notes	FAC-9d (+/- dB)	Notes	FAC-9e (+/- dB)	Notes	FAC-9f (+/- dB)	Notes	FAC-9g (+/- dB)	Notes	FAC-9h (+/- dB)	Notes
50		[c][f]		[c][f]		[c][f]		[d][f]		[d][f]		[d][f]		[b][d][f]
63		[c][f]		[d][f]		[b][d][f]		[b][d][f]		[b][d][f]		[b][d][f]		[b][d][f]
80	4.6		4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]	4.6	[c]
100	2.1		2.1		2.1		2.1		2.1		2.0		2.1	
125	1.8		1.8		1.8		1.8		1.9		1.8		1.8	
160	2.0		2.0		2.0		2.0		2.0		2.0		2.0	
200	0.8		0.9		0.8		0.9		0.8		0.9		0.8	
250	0.5		0.4		0.4		0.4		0.5		0.4		0.4	
315	0.4		0.5		0.5		0.4		0.5		0.5		0.4	
400	0.3		0.4		0.3		0.3		0.4		0.4		0.3	
500	0.3		0.3		0.4		0.4		0.4		0.4		0.4	[c]
630	0.3		0.3		0.3		0.3	[c]	0.3	[c]	0.3	[c]	0.3	[c]
800	0.3		0.3		0.3		0.3	[c]	0.3	[c]	0.3	[c]	0.3	[c]
1000	0.2		0.2		0.3		0.2	[c]	0.2	[c]	0.3	[c]	0.3	[c]
1250	0.2		0.2		0.2		0.2	[c]	0.2	[c]	0.2	[c]	0.2	[c]
1600	0.2		0.2		0.2	[c]	0.2	[c]	0.2	[c]	0.2	[d]	0.2	[d]
2000	0.2		0.2		0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
2500	0.2		0.2	[c]	0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
3150	0.2		0.2	[c]	0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
4000	0.2		0.2		0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
5000	0.2		0.2	[c]	0.2	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]
6300	0.2		0.3	[c]	0.2	[d]	0.2	[d]	0.2	[d]	0.2	[d]	0.3	[d]
8000	0.3		0.3	[d]	0.3	[d]	0.3	[d]	0.3	[d]	0.3	[d]	0.3	[d]
10000	0.5		0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]	0.5	[d]

Table M-1 Notes:

[b]: Specimen TL within 10 dB of facility flanking limits. No correction applied. Value represents lower bound for specimen TL in this band;

[c]: Specimen TL corrected for sound transmission through laboratory filler wall per requirements of ASTM E90-09 Annex A3;

[d]: Specimen TL too close to laboratory filler wall. Value represents lower bound for specimen TL in this band;

[f] Insufficient number of independent microphone samples to determine test uncertainty.

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14. ABSTRACT
Traditional composite aircraft structures are designed for load bearing and then overdesigned for impact damage and hot humid environments. Seeking revolutionary improvement in the performance and weight of composite structures, Cessna Aircraft Company, with sponsorship from the NASA Fundamental Aeronautics Program/Subsonic Fixed Wing Project, has developed and tested a protective skin concept which would allow the primary composite structure to carry only load and would meet the impact, hot and humid, and other requirements through protective skins. A key requirement for the protective skins is to make any impact damage requiring repair visible. Testing from the first generation of skins helped identify the most promising materials which were used in a second generation of test articles. This report summarizes lessons learned from the first generation of protective skins, the design and construction of the second-generation test articles, test results from the second generation for impact, electromagnetic effects, aesthetics and smoothing, thermal, and acoustic (for the first time), and an assessment of the feasibility of the protective skin concept.

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